



National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: October 7, 1998

In reply refer to: A-98-87

Honorable Jane F. Garvey
Administrator
Federal Aviation Administration
Washington, D.C. 20591

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On February 8, 1997, about 1935 Atlantic standard time, a Cessna 402, N318AB, operating under the provisions of Title 14 Code of Federal Regulations (CFR) Part 135 as Air Sunshine flight 319, crashed into the Caribbean Sea southwest of St. Thomas, U.S. Virgin Islands. The flight had been a regularly scheduled flight operating under visual flight rules (VFR) between St. Thomas and St. Croix. The airplane was destroyed; two passengers were killed, and the pilot and two of the remaining four passengers sustained minor injuries. Night, visual meteorological conditions prevailed at the time.

The pilot, who had accrued over 11,000 hours in the 400-series Cessna airplane types, mostly in the south Florida area, had begun flying in the Caribbean area less than a week before the accident. The pilot estimated that he had executed between 10 and 15 approaches to St. Thomas, with 4 or 5 of those at night. The pilot told Safety Board investigators that, at the time of the accident, he was unable to receive the distance measuring equipment¹ signal from St. Thomas. Consequently, he was especially attentive to receiving and establishing the proper localizer² course to St. Thomas to remain clear of the mountains on the north side of the island. The pilot said that he encountered some difficulties receiving the radio signal and was attempting to adjust the localizer course setting. During this time, the pilot noticed that the airplane was passing through 1,100 feet mean sea level. The pilot said that he refocused on the localizer and then the airplane struck the water about 3 miles from shore.

According to the pilot's account of the accident, the sky was dark and few or no lights were visible over the water. The evidence suggests that the absence of visual cues caused by the combination of dark sky and darkness over the water produced a "black hole" effect in which the pilot lost a visual sense of the airplane's height above water. As a result, the pilot misjudged the airplane's distance from the island and height above the water. Further, because the flight was conducted under

¹ Distance measuring equipment provides accurate information on the distance of the airplane from a properly equipped navigation aid.

² The localizer is a component of the instrument landing system that provides the pilot with lateral information.

VFR, the pilot had no assistance from air traffic control (ATC) regarding proximity to the surface, despite the approach path being within an area of ATC radar coverage. Had the pilot operated under instrument flight rules (IFR), radar would have enabled the controller to monitor the flight's altitude, as well as its position.

Radar advisories were also available to flights operating under VFR in the St. Thomas area. However, unlike IFR operations, VFR flights do not operate on standard routes with minimum safe altitudes that are published for pilots and controllers to use. As a result, controllers do not have a criterion for identifying VFR flights that are operating at unsafe altitudes. Further, the St. Thomas ATC facility incorporated the minimum safe altitude warning (MSAW) system, which is designed to alert a controller if an airplane descends prematurely toward terrain or water. However, to reduce the frequency of nuisance MSAW alerts from VFR flights operating below minimum IFR altitudes, the St. Thomas ATC radar MSAW system was configured by the Federal Aviation Administration (FAA) to alert controllers only about flights operating under IFR. The Safety Board notes that the FAA's configuration of the MSAW to exclude VFR operations is not unique to the St. Thomas ATC facility.

Although current rules allow aircraft used to provide scheduled passenger services under 14 CFR Part 135 (aircraft with fewer than 10 passenger seats) to be operated under VFR, the Safety Board is concerned that visual flight operations at night may impose incremental risks on users of these services. The hazards of night flight over large bodies of water have been recognized by the FAA and addressed in its Aeronautical Information Manual (AIM). The AIM section titled "Official Guide to Basic Flight Information and ATC Procedures" states the following:

Featureless terrain illusion—An absence of ground features, as when landing over water, darkened areas, and terrain made featureless by snow, can create the illusion that the aircraft is at a higher altitude than it actually is. The pilot who does not recognize this illusion will fly a lower approach.

The Safety Board previously addressed the risks of operating scheduled passenger flights under VFR in its investigation of a 1989 accident involving a DeHavilland DHC 6-300, conducted under 14 CFR Part 135, that crashed into the side of a mountain in Molokai, Hawaii, while the pilot was attempting to operate under VFR during IFR conditions.³ As a result of that accident, in Safety Recommendation A-90-137, the Safety Board urged the FAA to require that scheduled 14 CFR Part 135 operations of turbine-powered or multiengine airplanes be conducted under IFR during hours of darkness or whenever visibilities less than 3 miles or ceilings less than 1,000 feet are forecast, reported, or encountered. The FAA replied to the Safety Board that it agreed with the intent of the recommendation. In 1996, the FAA further responded to the Safety Board by citing the promulgation of the commuter rule, which changed the regulatory basis of scheduled passenger operations using aircraft with 10 or more passenger seats from 14 CFR Part 135 to Part 121. Based on this action and the existing Part 121 restrictions on VFR operations, on July 15, 1996, Safety Recommendation A-90-137 was classified "Closed—Acceptable Action."

³ See *Aloha IslandAir, Inc., Flight 1712, DeHavilland Twin Otter, DHC-6-300, N707PV, Halawa Point, Molokai, Hawaii, October 28, 1989*. Aviation Accident Report NTSB/AAR-90/05. Washington, DC.

Although the FAA's action in response to Safety Recommendation A-90-137 has continued to be effective for operations that use 10-seat and larger aircraft, the St. Thomas accident indicates that VFR operations at night continue to pose a hazard to passengers on scheduled flights that use smaller aircraft. Passengers on these flights should be provided the additional safety benefits that result from using IFR procedures and receiving radar traffic and terrain advisories when their flights are operated at night. These benefits include the restriction of operations to published routes or areas where ATC can provide radar vectors and the MSAW system. Most 14 CFR Part 135 scheduled passenger flights should be able to operate under IFR. However, the Safety Board recognizes that some of these flights may not be able to operate under IFR because of the lack of necessary ground navigational aids and instrument approach procedures or the characteristics of the airplanes being used. (Commercial, passenger-carrying operations are not permitted to fly under IFR in many single-engine airplane types.)

Therefore, the National Transportation Safety Board makes the following recommendation to the Federal Aviation Administration:

Require all 14 Code of Federal Regulations Part 135 scheduled passenger flights that are operated at night to be conducted under instrument flight rules, with any exceptions to be provided in air carrier operations specifications on a route-by-route basis when instrument flight rules operations are found to be unfeasible. (A-98-87)

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in this recommendation.

By:



Jim Hall
Chairman



National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: November 30, 1998

In reply refer to: A-98-88 through -106

Honorable Jane F. Garvey
Administrator
Federal Aviation Administration
Washington, D.C. 20591

About 1554 eastern standard time,¹ on January 9, 1997, an Empresa Brasileira de Aeronautica, S/A (Embraer) EMB-120RT, N265CA, operated by COMAIR Airlines, Inc.,² as flight 3272, crashed during a rapid descent after an uncommanded roll excursion near Monroe, Michigan. Comair flight 3272 was being operated under the provisions of Title 14 Code of Federal Regulations (CFR) Part 135 as a scheduled, domestic passenger flight from the Cincinnati/Northern Kentucky International Airport (CVG), Covington, Kentucky, to Detroit Metropolitan/Wayne County Airport (DTW), Detroit, Michigan. The flight departed CVG about 1508, with 2 flightcrew members, 1 flight attendant, and 26 passengers on board. There were no survivors. The airplane was destroyed by ground impact forces and a postaccident fire. Instrument meteorological conditions prevailed at the time of the accident, and flight 3272 was operating on an instrument flight rules flight plan.

The National Transportation Safety Board determined that the probable cause of this accident was the Federal Aviation Administration's (FAA) failure to establish adequate aircraft certification standards for flight in icing conditions, the FAA's failure to ensure that a Centro Tecnico Aeroespacial/FAA-approved procedure for the accident airplane's deice system operation was implemented by U.S.-based air carriers, and the FAA's failure to require the establishment of adequate minimum airspeeds for icing conditions, which led to the loss of control when the airplane accumulated a thin, rough accretion of ice on its lifting surfaces.³

¹ Unless otherwise indicated, all times are eastern standard time, based on a 24-hour clock.

² Within this safety recommendation letter, COMAIR Airlines, Inc., will be identified as Comair.

³ National Transportation Safety Board. 1998. *In-Flight Icing Encounter and Uncontrolled Collision With Terrain, Comair Flight 3272, Embraer EMB-120RT, N265CA, Monroe, Michigan, January 9, 1997. Aircraft Accident Report NTSB/AAR-98/04.* Washington, DC.

Summary of Accident Sequence

According to cockpit voice recorder (CVR) and air traffic control (ATC) information, during the 20 minutes preceding the accident, the pilots received a series of clearances from ATC that included descent, airspeed, and heading instructions. Flight data recorder (FDR) and radar data indicated that the airplane's descent from the en route cruise altitude of flight level 210 to 4,000 feet mean sea level (msl) was stable and controlled and was accomplished at airspeeds and headings consistent with those assigned by ATC. Meteorological information and pilot reports indicated that the airplane was probably intermittently in clouds as it descended between about 11,000 feet msl and 8,200 feet msl; below 8,200 feet msl, the airplane was probably operating predominantly in the clouds.

The pilots were operating with the autopilot engaged during the descent. They had completed the descent checklist (including the activation of the propeller deicing and windshield heat at the ice protection checklist prompt) and the first four of the six items on the approach checklist⁴ before the airplane reached 4,000 feet msl during its descent. At 1553:59, when the autopilot was leveling the airplane at 4,000 feet msl on a heading of 180°, the airplane was in the clean configuration (no flaps or gear extended) at an airspeed of about 166 knots (the pilots were beginning to reduce the airspeed to the ATC-assigned airspeed of 150 knots). At that time, ATC instructed the pilots of flight 3272 to turn left to a heading of 090°. Shortly after the pilots initiated the left turn (by selecting the assigned heading for the autopilot), the airplane reached its selected altitude and (at 1554:08) the autopilot automatically transitioned to the altitude hold mode. As the autopilot attempted to maintain the selected altitude, the airplane's angle-of-attack (AOA) began to increase and the airspeed continued to decrease; at 1554:10, the autopilot began to trim the elevator (pitch trim) to an increasingly nose-up position.

The accident airplane's FDR data indicated that at 1554:10 the airplane's left bank steepened beyond 20° (moving toward the autopilot's command limit in the heading mode of 25°, +/- 2.5°). At that point (according to the autopilot design and FDR information), the roll rate exceeded that required by the autopilot's design logic to achieve the commanded roll angle, and the autopilot's input to the aileron servos moved the ailerons (and thus the airplane's control wheel) in the right-wing-down (RWD) direction to counter the increasing left roll rate. FDR data indicated that, during the next 3 seconds, the left and right AOA vanes began to diverge, indicating a left sideslip/yaw condition, and the lateral acceleration values began to increase to the left while the autopilot increased the control wheel input to the right in an attempt to control the roll. Thus, by 1554:10, as the airspeed decreased through 155 knots, the airplane experienced the beginning of a significant asymmetry in the lift distribution between the right and left wings and an uncommanded yaw and roll to the left.⁵ The roll and control wheel position parameters continued to trend in opposite directions, and the left and right AOA vanes continued to split for the next 14 seconds, until the autopilot disconnected at 1554:24.125.

⁴ According to several Comair EMB-120 pilots, the remaining approach checklist items—flight attendants, notified and flaps, 15/15/checked—would normally be accomplished later during the approach, as the airplane neared the destination airport.

⁵ Evaluation of the FDR information revealed that a slight asymmetry of lift because of ice existed earlier in the flight; however, it became aerodynamically significant about 1554:10.

Just after 1554:15, as the airplane's airspeed began to decrease below 150 knots, the pilots began to increase the engine power;⁶ however, the airplane's airspeed continued to decrease. When the captain drew the first officer's attention to the low airspeed indication at 1554:20.8, the airplane's airspeed had decreased to 147 knots. During the next 2 seconds, the pilots more aggressively increased the engine power, and a significant torque split occurred; the torque values peaked at 108 percent on the left engine and 138 percent on the right engine. The Safety Board considered several possible reasons for the significant torque split, including uneven throttle movement by the pilots, ice ingestion by the left engine, a misrigged engine, or an improper engine trim adjustment on the newly installed right engine; however, it was not possible to positively determine the cause of the torque split. Postaccident simulations indicated that this torque split had a significant yaw-producing effect at a critical time in the upset event, exacerbating the airplane's excessive left roll tendency. The airplane's airspeed decreased further to 146 knots, the left roll angle increased beyond the autopilot's 45° limit, and (at 1554:24.1) the autopilot disconnect warning began to sound. One second later, the stick shaker activated. The sudden disengagement of the autopilot (at 1554:24.125) greatly accelerated the left rolling moment that had been developing, suddenly putting the airplane in an unusual attitude. Although the pilots were likely surprised by the upset event, interpretation of the FDR data indicated that the pilots responded with control wheel inputs to counter the left roll within 1 second of the autopilot disengagement and continued to apply control inputs in an apparent attempt to regain control of the airplane until the FDR recording ceased.

Meteorological Factors

Although Comair flight 3272 was operating in winter weather conditions throughout its flight from the Cincinnati area to Detroit, CVR and weather information indicated that the airplane was operating above the cloud tops at its cruise altitude of 21,000 feet msl. Further, the temperatures at the altitudes flown during the en route phase of the flight were too cold to be conducive to airframe ice accretion, and examination of the FDR data did not reflect degraded airplane performance until later in the airplane's descent. Therefore, the Safety Board concludes that the airplane was aerodynamically clean, with no effective ice accreted, when it began its descent to the Detroit area.

A study conducted by the National Center for Atmospheric Research (NCAR) indicated that there was strong evidence for the existence of icing conditions in the clouds along the accident airplane's descent path below 11,000 feet msl. In addition, weather radar data showed generally light precipitation intensities in the area west of Detroit, with weather echoes of increasing intensity below 11,000 feet msl along the airplane's descent path. The weather radar data indicated that the highest precipitation intensities likely existed between 4,100 feet msl and 3,900 feet msl.

⁶ An engine torque split manifested itself during this application of power—at 1554:17, the FDR recorded torque values of 33.3 percent and 39.3 percent on the left and right engines, respectively. The engine torque split ranged from 6 to 10 percent between 1554:17 and 1554:22, when torque values (and the range of the torque split) began to increase abruptly. Simulator test flights that replicated the accident scenario demonstrated that the initial 6 to 10 percent torque split did not have a large aerodynamic effect on the airplane's left roll; however, the larger torque split that occurred later in the accident sequence had a significant aerodynamic effect.

The NCAR research meteorologists reported that the average liquid water content (LWC) in the clouds near the accident site likely varied from 0.025 to 0.4 grams per cubic meter when averaged over the cloud depth. However, according to an NCAR research meteorologist, droplet size and LWC are rarely evenly distributed through the depth of a cloud; he stated that, in a typical cloud distribution, the larger droplet sizes with corresponding lower LWC would likely exist near the cloud bases, whereas smaller droplet sizes with higher LWC would typically exist near the cloud tops. He stated that the accident airplane might have encountered higher LWC values (0.5-0.8 grams per cubic meter) with smaller droplets (non-supercooled large droplets (SLD), 10-30 microns) near the cloud tops and lower LWC values (0.025 to 0.4 grams per cubic meter) with larger droplets (larger than 30 microns) near the cloud bases (consistent with the previously discussed weather radar data). Further, the NCAR research meteorologist stated, "if any SLD existed...it would have been more likely to be lower in the cloud...be mixed with smaller drops...the larger drops in the spectrum of those that may have existed there would have been in the 200-400 micron...range."

In addition, the accident airplane's descent path passed through an area of relatively low radar reflectivity during the 4 to 5 minutes before the accident. According to the NCAR report, the area of reduced reflectivity indicated that "the snow-making process was less efficient there, thus allowing a greater opportunity for liquid cloud to exist." Postaccident statements obtained from the other pilots who were operating along the accident airplane's flightpath (and passed through the area of low reflectivity) near the time of the accident indicated that they encountered widely variable conditions. For example, the pilots of Cactus 50 reported moderate rime icing with the possibility of freezing drizzle, the pilots of Northwest Airlines (NW) flight 272 encountered moderate-to-severe rime icing as soon as they leveled off at 4,000 feet msl, and the pilots of NW flight 483 reported no icing.

Comparison of data from the airplanes indicates that the differences in airframe ice accretion reported by the pilots can be attributed to slight differences in timing, altitude, location (ground track), airspeed, and icing exposure time (and time within the area of reduced reflectivity) of the airplanes. Based on weather radar information and pilot statements, the Safety Board concludes that the weather conditions near the accident site were highly variable and were conducive to the formation of rime or mixed ice at various altitudes and in various amounts, rates, and types of accumulation; if SLD icing conditions were present, the droplet sizes probably did not exceed 400 microns and most likely existed near 4,000 feet msl.

Aerodynamic Effect of the Ice Accretion

To help assess the type, amount, and effect of the ice that might have been accumulated by Comair flight 3272 during its descent, the Safety Board reviewed the available icing and wind tunnel research data, conducted additional airplane performance studies/simulations, and requested the National Aeronautics and Space Administration's (NASA's) assistance in conducting icing research tunnel (IRT) tests and computational studies. In addition, the Safety Board reviewed wind tunnel test data obtained during research conducted by the FAA at the University of Illinois at Urbana/Champaign (UIUC).

The Safety Board's study of the accident airplane's aerodynamic performance indicated that it began to degrade from ice accumulation⁷ about 4½ to 5 minutes before the autopilot disengaged, as the airplane descended through 7,000 feet msl; the amount of degradation increased gradually as the airplane descended to 4,000 feet msl. Based on this gradual performance degradation, weather radar data that showed light precipitation intensities, pilot reports of moderate or less ice accretions,⁸ and the Safety Board and NCAR weather studies, it appeared likely that Comair flight 3272 encountered icing conditions that fell within the 14 CFR Part 25 appendix C envelope⁹ and/or the lower portion of the SLD icing range during its descent to 4,000 feet msl. Thus, the postaccident icing tunnel tests were performed using LWCs between 0.52 and 0.85 grams per cubic meter and water droplet sizes between 20 microns and 270 microns. Total air temperatures (TAT) used in the icing tunnel tests ranged between 26° F and 31° F (-3° C and -0.5° C),¹⁰ consistent with the static air temperature (SAT) values recorded by the FDR during the airplane's descent from 7,000 to 4,000 feet msl. The exposure time used in the icing tunnel tests was 5 minutes; additional runs were conducted under some test conditions to determine the effect that deicing boot activation had on cleaning the leading edge and on subsequent ice accretions.

The icing tunnel tests did not result in thick ice accumulation under any test condition (including SLD droplets); rather, the tests consistently resulted in a thin (0.25 inch accumulation or less), rough "sandpaper-type" ice coverage over a large portion of the airfoil's leading edge deicing boot surface area (and aft of the deicing boot on the lower wing surface in some test conditions). In addition, in many IRT test conditions, small (½ inch) ice ridges accreted along the leading edge deicing boot seams. According to NASA and Safety Board IRT test observers, the thin, rough ice coverages (and ice ridges, where applicable) that accreted on the EMB-120 wing were somewhat translucent and were often difficult to perceive from the observation window. The IRT observers further noted that IRT lighting conditions and cloud (spray) type greatly affected the conspicuity of the ice accumulation, making it difficult to perceive the ice accumulation during the icing exposure periods. Scientists at NASA's Lewis Research Center described the IRT ice accretions as mostly "glaze" ice, like mixed or clear ice in nature, although it looked slightly like rime ice when the IRT was brightly lighted for photographic documentation of the ice accretions because of its roughness. The Safety Board notes that it is possible that such an accumulation would be difficult for pilots to perceive visually during flight, particularly in low light conditions. This type of accumulation would be consistent with the accident airplane's CVR, which did not record any crew discussion of perceived ice accumulation and/or the need to activate deicing boots during the last 5 minutes of the accident flight.

⁷ Although the Safety Board considered other possible sources for the aerodynamic degradation (such as a mechanical malfunction), the physical evidence did not support a system or structural failure, and the FDR data indicated a gradual, steadily increasing performance degradation that was consistent with degradation observed by the Safety Board in data from events in which icing was a known factor.

⁸ All pilot reports indicated moderate or less ice accretions, except the pilots of NW flight 272, who reported that they encountered a trace of rime ice during the descent, then encountered moderate-to-severe icing at 4,000 feet msl about 2 minutes after the accident.

⁹ The Part 25 appendix C icing envelope specifies the water drop mean effective diameter, the LWC, and the temperatures at which the airplane must be able to safely operate; aircraft compliance must be demonstrated through analysis, experimentation, and flight testing.

¹⁰ These TATs are equivalent to SATs of 21° F (-6° C) to 25.5° F (-3° C).

The location of rough ice coverage observed during the icing tunnel tests varied, depending on AOA; at lower AOAs, the ice accretions extended farther aft on the upper wing surface (to the aft edge of the deicing boot on the upper wing surface, about 7 percent of the wing chord at the aileron midspan), whereas at higher AOAs, the ice accretions extended farther aft on the lower wing surface. In some IRT test conditions, sparse feather-type ice accretion extended aft of the deicing boot coverage on the lower wing surface (which extends to about 10½ percent of the airfoil chord at the aileron midspan) as far as 30 to 35 percent of the airfoil's chord.¹¹

The density of the rough ice coverage also varied, depending on the exposure time; a sparse layer of rough ice usually accreted on the entire impingement area during the first 30 seconds to 1 minute of exposure, and the layer became thicker and more dense as exposure time increased. The NASA-Lewis and FAA/UIUC tests indicated that thin, rough ice accretions located on the leading edge and lower surface of the airfoil primarily resulted in increases in drag, while thin, rough ice accretions located on the leading edge and upper wing surface had an adverse effect on both lift and drag; this is consistent with information that has been obtained during National Advisory Committee for Aeronautics (NACA)/NASA icing research conducted since the late 1930s. Data from research conducted in the 1940s and 1950s indicate that an airfoil's performance can be significantly affected by even a relatively small amount of ice accumulated on the leading edge area, if that accumulation has a rough, sandpaper-type surface.

Consistent with these data, NASA's drag calculations indicated that the thin, rough layer of sandpaper-type ice accumulation resulted in significant drag and lift degradation on the EMB-120 wing section. Further, the thin rough ice accumulation resulted in a decrease in stall AOA similar to that observed in wind tunnel tests with 3-inch ram's horn ice shapes on protected surfaces and frequently demonstrated a more drastic drop off/break at the stall AOA. FAA/UIUC conducted wind tunnel tests using generic shapes to represent the sandpaper-type roughness with ridges placed on the upper wing surface at 6 percent of the wing chord (farther aft than the ice ridges observed during NASA's IRT tests); these tests further demonstrated that the ridge type of ice accretion resulted in more adverse aerodynamic effect than the 3-inch ram's horn ice shapes.

As previously noted, NASA's IRT tests indicated that when an EMB-120 wing is exposed to conditions similar to those encountered by Comair flight 3272 before the accident, the airfoil tended to accrete a small ice ridge (or ridges) along the deicing boot tube segment stitchlines.

¹¹ According to NASA-Lewis scientists, some of the frost accretion observed aft of the deicing boot on the lower wing surface during the icing tunnel tests might have been an artifact of the icing research tunnel (resulting from the higher turbulence, humidity, and heat transfer characteristics of the tunnel). However, the B.F. Goodrich ice impingement study (which predicts ice accretion impingement limits on an airfoil) and NASA's LEWICE computer program (which predicts the extent of ice accretion on the leading edges of airplane wings and impingement limits and ice thickness for specified conditions but cannot predict surface roughness features) also predicted a sparse, rough ice accretion aft of the deicing boot on the lower wing surface for some of the tested conditions. However, no ice accretion aft of the deicing boot was noticed during the natural icing certification tests. Although it is possible that some of the drag observed in the accident airplane's performance was the result of a sparse, rough ice accumulation aft of the deicing boot on the lower wing surface, it was not possible to positively determine whether the accident airplane's ice accretion extended beyond the deicing boot coverage.

During tests conducted at a TAT of 26° F, a small, but prominent (1/2 inch) ridge of ice frequently appeared on the forward portion (0.5 to 1 percent mean aerodynamic chord) of the leading edge deicing boot's upper surface.

The IRT test results were used in NASA's computational studies, which indicated that these pronounced ice ridges tended to act as stall strips, creating more disrupted airflow over the airfoil's upper surface, further decreasing the lift produced by the airfoil, and resulting in a lower stall AOA than the rough ice accretions alone. NASA's computational study data indicated that a thin, rough ice accretion with a small, prominent ice ridge can result in a lower stall AOA and a more dramatic drop off/break than the 3-inch ram's horn ice shape commonly used during initial icing certification testing.

The accident airplane's performance displayed evidence of adverse effects on both lift and drag during the airplane's descent to 4,000 feet msl. The degradation exhibited by the accident airplane was consistent with a combination of thin, rough ice accumulation on the impingement area (including both upper and lower wing leading edge surfaces), with possible ice ridge accumulation. Thus, based on its evaluation of the weather, radar, drag information, CVR, existing icing research data, and postaccident icing and wind tunnel test information, the Safety Board concludes that it is likely that Comair flight 3272 gradually accumulated a thin, rough glaze/mixed ice coverage on the leading edge deicing boot surfaces, possibly with ice ridge formation on the leading edge upper surface, as the airplane descended from 7,000 feet msl to 4,000 feet msl in icing conditions; further, this type of ice accretion might have been imperceptible to the pilots.

The Safety Board notes that FAA Order 7110.10L, "Flight Services," contains a definition of "trace" ice accumulations, that states, in part, "A trace of ice is when ice becomes perceptible....It is not hazardous even though deicing/anti-icing equipment is not utilized unless encountered for an extended period of time [over 1 hour]." Information obtained during this investigation, which echoed the results of research conducted in the 1930s and 1940s, indicated that thin, rough amounts of ice, even in trace amounts can result in hazardous flight conditions. The Safety Board concludes that the suggestion in current FAA publications that "trace" icing is "not hazardous" can mislead pilots and operators about the adverse effects of thin, rough ice accretions. Therefore, the Safety Board believes that the FAA should amend the definition of trace ice contained in FAA Order 7110.10L, "Flight Services," (and in other FAA documents as applicable) so that it does not indicate that trace icing is not hazardous.

The Safety Board notes that in some icing exposure scenarios, pilots could become aware of the performance degradation without observing a significant accumulation of ice on the airplane by observing other cues, such as a decrease in airspeed, excessive pitch trim usage, a higher-than-normal amount of engine power needed to maintain a stabilized condition, and/or anomalous rates of climb or descent. However, the Safety Board concludes that because the pilots of Comair flight 3272 were operating the airplane with the autopilot engaged during a series of descents, right and left turns, power adjustments, and airspeed reductions, they might not have perceived the airplane's gradually deteriorating performance.

Further, although it is possible (based on the icing reported by the pilots of NW flight 272 and the NCAR scientist's estimation of the likely droplet size distribution in the clouds) that the accident flight encountered SLD icing¹² as it reached 4,000 feet msl, the airplane was only at that altitude for about 25 seconds before the upset occurred; during most of that 25 seconds, the FDR data showed that the autopilot was countering the increasing left roll tendency and a sideslip condition was developing. However, even if the accident flight had accumulated ice at the rapid rate reported by the pilots of NW flight 272 (about $\frac{1}{2}$ inch per minute), the accident flight could not have accumulated a large amount of ice during the brief period of time it spent at 4,000 feet before the autopilot disengaged and the loss of control occurred. Further, icing of the magnitude described by the pilots of NW flight 272 would have produced strong visual cues, and it is likely that the pilots would have commented on such a rapid accumulation, had it occurred. The accident airplane's CVR did not record any flightcrew comments about ice accumulation or the need to activate the leading edge deicing boots during the last 5 minutes of the accident flight; this is consistent with an ice accumulation that was either not observed by the pilots or that was observed but considered to be unremarkable.

Use of Deice/Anti-ice Equipment

The Safety Board attempted to determine whether the airplane's ice protection systems were operated during the accident airplane's descent and approach to DTW. CVR information showed that when the pilots performed the descent checklist at 1547, they confirmed that the airplane's "standard seven" anti-ice systems were activated and activated the windshield heat and the propeller deice system.¹³ This was consistent with guidance contained in Comair's EMB-120 Flight Standards Manual (FSM), which stated that anti-ice systems should be activated "before flying into known icing conditions" to prevent ice accumulation on the affected surfaces. Comair's EMB-120 FSM defined icing conditions as existing "when the OAT [outside air temperature] is $+5^{\circ}$ C or below and visible moisture in any form is present (such as clouds, rain, snow, sleet, ice crystals, or fog with visibility of one mile or less)."

For years, airplane manufacturers have incorporated leading edge deicing boots in the design of airplanes that are to be certificated for operation in icing conditions; the purpose of deicing boots is to shed the ice that accumulates on protected surfaces of the airframe. Over the years, leading edge deicing boots have demonstrated their effectiveness to operators and pilots by keeping the wing and tail leading edges relatively clear of aerodynamically degrading ice accumulations, to the point that operators and pilots have become confident that the airplanes can be flown safely in icing conditions as long as the airplane's deicing boots are operated (and functioning) properly. However, based on problems with earlier deicing boot designs (which used larger tubes and lower pressures, resulting in slower inflation/deflation rates), manufacturers, operators, and pilots developed the belief that premature activation of the leading edge deicing boots could (as cautioned in Comair's EMB-120 FSM) "result in the ice forming the shape of an

¹² Results from the SLD icing tanker tests suggest that the visual cues for SLD ice accumulations (unusually extensive ice accreted on the airframe in areas not normally observed to collect ice, accumulation of ice on the upper surface of the wing aft of the protected area, and on the propeller spinner farther aft than normally observed) would have been very apparent to the pilots and might have resulted in a comment.

¹³ Although Embraer's nomenclature identifies the propeller ice protection mechanism as a deicing system, it functions as an anti-icing system because it is activated before ice accumulates on the airframe.

inflated de-ice boot, making further attempts to deice in flight impossible [ice bridging].” Thus, at the time of the accident, Comair’s (and most other EMB-120 operators’) guidance indicated that pilots should delay activation of the leading edge deicing boots until they observed $\frac{1}{4}$ inch to $\frac{1}{2}$ inch ice accumulation, despite Embraer’s FAA and Centro Tecnico Aeroespacial of Brazil (CTA) approved EMB-120 Airplane Flight Manual (AFM) revision 43, which indicated that pilots should activate the leading edge deicing boots at the first sign of ice accumulation.

The pilots’ activation of the propeller and windshield ice protection systems when the airplane entered the clouds would indicate that they were aware that the airplane was operating in icing conditions. If they had activated the leading edge deicing boots, at least some of the airplane’s degraded performance would have been restored. However, even if the pilots observed any of the thin, rough ice accretion that likely existed before the loss of control, they probably would not have activated the deicing boots because Comair’s guidance to its pilots advised against activating the deicing boots until they observed a thicker ice accumulation. Therefore, based on CVR information and on the steady degradation of airplane performance that was clearly uninterrupted by leading edge deicing boot activation, the Safety Board concludes that, consistent with Comair’s procedures regarding ice protection systems, the pilots did not activate the leading edge deicing boots during their descent and approach to the Detroit area, likely because they did not perceive that the airplane was accreting significant (if any) structural ice.

During the postaccident (November 1997) Airplane Deicing Boot Ice Bridging Workshop, information regarding recent icing tunnel and flight test research into the ice bridging phenomenon was disseminated and discussed among industry personnel. The recent research revealed that modern turbine-powered airplanes, with their high-pressure, segmented pneumatic deicing boots, are not at risk for ice bridging.¹⁴ However, in April 1996 when Embraer issued (FAA- and CTA-approved) revision 43 to the EMB-120 AFM, the procedure it recommended—activation of the leading edge deicing boots at the first sign of ice accretion—was not consistent with traditional industry concerns about ice bridging. According to the FAA’s EMB-120 Aircraft Certification Program Manager, when the EMB-120 AFM revision was proposed by Embraer in late 1995, the deicing boot procedural change was very controversial and generated numerous discussions among FAA and industry personnel. The FAA’s EMB-120 Aircraft Certification Program Manager stated that the aircraft evaluation group (AEG) personnel involved in the discussions about the six EMB-120 icing-related events, the EMB-120 in-flight icing tanker tests, and the deicing boot procedural change were initially resistant to the deicing boot procedural change because of the perceived potential for ice bridging.

The Safety Board notes that during the winter of 1995/1996, senior Comair personnel (and representatives from other EMB-120 operators) were involved in numerous meetings and discussions regarding the six preaccident icing-related events and that they subsequently received Embraer’s Operational Bulletin (OB) 120-002/96 and revision 43 to the EMB-120 AFM, with its controversial deicing boot procedural change. Although these discussions and documents apparently heightened senior Comair personnel’s awareness and concern about EMB-120 operations in icing conditions (as evidenced by the December 1995 interoffice memo, entitled

¹⁴ It is important to note that ice bridging may still be a potential hazard for airplanes with older technology deicing boots that have slower inflation/deflation rates.

“Winter Operating Tips,” and the October 1996 flight standards bulletin (FSB) 96-04, entitled “Winter Flying Tips”), until the (postaccident) ice bridging workshop, there was insufficient information available to allay the company’s concerns regarding the perceived hazards of ice bridging. Because Comair management personnel were still concerned that ice bridging was a problem for modern turbopropeller-driven airplanes, at the time of the accident, the company’s deicing boot activation procedures had not been revised in accordance with AFM revision 43. The Safety Board recognizes the concerns regarding ice bridging that Comair had at the time of the accident (before the ice bridging workshop) and notes that the FAA had not mandated incorporation of the procedural revision or engaged in discussions with EMB-120 operators/pilots regarding the merit of the procedural change. Apparently, Comair was not the only EMB-120 operator with concerns regarding the deicing boot procedural change because the air carriers’ records indicated that at the time of the accident, only two of seven U.S.-based EMB-120 operators had incorporated the revision into its procedural guidance. However, the Board is concerned that Comair’s EMB-120 pilots did not have access to the most current information regarding operating the EMB-120 in icing conditions.

The Safety Board concludes that had the pilots of Comair flight 3272 been aware of the specific airspeed, configuration, and icing circumstances of the six previous EMB-120 icing-related events and of the information contained in OB 120-002/96 and revision 43 to the EMB-120 AFM, it is possible that they would have operated the airplane more conservatively with regard to airspeed and flap configuration or activated the deicing boots when they knew they were in icing conditions. Therefore, the Safety Board believes that the FAA should require principal operations inspectors (POIs) to discuss the information contained in AFM revisions and/or manufacturers’ OBs with affected air carrier operators and, if the POI determines that the information contained in those publications is important information for flight operations, to encourage the affected air carrier operators to share that information with the pilots who are operating those airplanes.

According to EMB-120 pilots from Comair and the Air Line Pilots Association (ALPA), their discussions with other EMB-120 flightcrews indicate that the procedural change is still a controversial issue, despite the information revealed during this accident investigation and at the November 1997 Airplane Deicing Boot Ice Bridging Workshop. This illustrates how thoroughly ingrained the ice bridging concept was in pilots and operators and the importance of an ice bridging pilot education program. Therefore, a thin, yet performance-decreasing type of ice (similar to that likely accumulated by Comair flight 3272) can present a more hazardous situation than a 3-inch ram’s horn ice accumulation because it would not necessarily prompt the activation of the boots. Based on this information, the Safety Board concludes that the current operating procedures recommending that pilots wait until ice accumulates to an observable thickness before activating leading edge deicing boots results in unnecessary exposure to a significant risk for turbopropeller-driven airplane flight operations. Based primarily on concerns about ice bridging, pilots continue to use procedures and practices that increase the likelihood of (potentially hazardous) degraded airplane performance resulting from small amounts of rough ice accumulated on the leading edges.

The Safety Board is aware that the FAA, NASA, and ALPA plan to organize an industry-wide air carrier pilot training campaign to increase pilots’ understanding of the ice bridging

phenomenon and safe operation of deicing boots. Unfortunately, according to NASA personnel, the training program has not yet begun because the FAA is still developing its position based on information from the Ice Bridging Workshop. The Safety Board appreciates the FAA's intention to initiate the development of ice bridging training and its desire to ensure that the training is as thorough and accurate as possible; however, the Board is concerned that the planned training is being delayed. Further, the planned training primarily targets air carrier pilots, and the Board considers it important that the information be disseminated to all affected pilots/operators. The Safety Board is concerned that if nonair carrier pilots and operators do not receive the training, they may operate turbopropeller-driven airplanes in icing conditions using deicing boot procedures that result in less safe flight operations. A training program that reaches only a limited part of the pilot population may not be sufficient to eliminate the pervasive beliefs regarding the potential for ice bridging in turbopropeller-driven airplanes.

Therefore, the Safety Board believes that the FAA should (with NASA and other interested aviation organizations) organize and implement an industry-wide training effort to educate manufacturers, operators, and pilots of air carrier and general aviation turbopropeller-driven airplanes regarding the hazards of thin, possibly imperceptible, rough ice accumulations, the importance of activating the leading edge deicing boots as soon as the airplane enters icing conditions (for those airplanes in which ice bridging is not a concern), and the importance of maintaining minimum airspeeds in icing conditions. The Safety Board encourages the FAA and NASA to expedite this training effort. Further, because ice bridging is not a concern in modern turbopropeller-driven airplanes and because thin amounts of rough ice can be extremely hazardous, the Safety Board believes that the FAA should require manufacturers and operators of modern turbopropeller-driven airplanes in which ice bridging is not a concern to review and revise the guidance contained in their manuals and training programs to include updated icing information and to emphasize that leading edge deicing boots should be activated as soon as the airplane enters icing conditions.

It is important to note that although leading edge deicing boots are useful in minimizing the adverse affects of ice accumulation on an airplane's protected surfaces, activation of deicing boots does not result in a completely clean boot surface; some residual ice remains on the deicing boot after it cycles, and intercycle ice accumulates between deicing boot cycles (on the EMB-120, during the 54-second or 174-second intervals, depending on the mode of boot operation selected). Icing tunnel tests indicate that when the deicing boots are activated early, the initial deicing boot cycle leaves a higher percentage of residual ice than it would with delayed deicing boot activation. However, when the deicing boots remained operating during the remainder of the ice encounter, subsequent deicing boot cycles resulted in a wing leading edge about as clean as would occur with delayed boot activation.

The FAA/UIUC wind tunnel tests revealed that even a thin, sparse (5 percent to 10 percent density ice coverage) amount of rough ice accumulation over the leading edge deicing boot coverage area resulted in significant aerodynamic degradation. This information raises questions about the effectiveness of leading edge deicing boots when dealing with this type of ice accumulation, especially considering a B.F. Goodrich estimation that a good, effective deicing boot shed leaves about 20 percent of the accumulated ice on the boots. The sparse ice coverage observed during the first 30 to 60 seconds of exposure time in some of NASA's icing tunnel

test conditions (and which could occur between deicing boot cycles) was estimated by observers to be about 10 percent. This combined research indicates that it is possible for a hazardous situation to occur even if pilots operate the deicing boots early and throughout the icing encounter. The Westair flight 7233 incident, in which uncommanded roll and pitch excursions occurred despite the fact that the pilots stated that they had activated the leading edge deicing boots and selected the heavy boot operation mode,¹⁵ may be an example of such a hazardous situation.

In addition, a hazardous situation may develop even if deicing boots are operated throughout an icing encounter as a result of ice accretions on an airplane's unprotected surfaces, such as aft of the deicing boots. The B.F. Goodrich impingement study, NASA's LEWICE calculations, and NASA IRT tests indicated that a light accretion may occur on the unprotected lower wing surfaces aft of the deicing boot on the EMB-120. However, Embraer representatives stated that such an ice accretion would result in only a trace of ice accumulating aft of the deicing boots and would have a minimal aerodynamic penalty in drag only. Although there was no evidence of ice accretion aft of the deicing boot during the EMB-120 certification natural icing tests and it was not possible to determine whether the accident airplane's ice accretion extended aft of the deicing boot coverage, it is possible that ice accretion on the unprotected surface aft of the deicing boot could exacerbate a potentially hazardous icing situation.

Based on icing and wind tunnel research and information from the Westair incident, the Safety Board concludes that it is possible that ice accretion on unprotected surfaces and intercycle ice accretions on protected surfaces can significantly and adversely affect the aerodynamic performance of an airplane even when leading edge deicing boots are activated and operating normally. Thus, pilots can minimize (but not always prevent) the adverse effects of ice accumulation on the airplane's leading edges by activating the leading edge deicing boots at the first sign of ice accretion. It is not clear what effect residual ice/ice accretions on unprotected nonleading edge airframe surfaces have on flight handling characteristics. Because not enough is known or understood about icing in general, and especially about the effects of intercycle and residual ice, the Safety Board believes that the FAA should (with NASA and other interested aviation organizations) conduct additional research to identify realistic ice accumulations, to include intercycle and residual ice accumulations and ice accumulations on unprotected surfaces aft of the deicing boots, and to determine the effects and criticality of such ice accumulations; further, the information developed through such research should be incorporated into aircraft certification requirements and pilot training programs at all levels.

The Safety Board considers it likely that future ice detection/protection systems will decrease the hazards associated with icing by incorporating ice detection and protection (automatic activation of deicing boots or anti-icing systems) for individual surfaces, including the horizontal stabilizers, of all airplanes certificated for flight in icing conditions. However, because ice accretions and their effects are not yet fully understood, the Safety Board concludes that

¹⁵ According to the pilots of Westair flight 7233, they were aware that they were operating in "icing conditions;" they stated that they observed ice accumulating on the airplane and had activated the leading edge deicing boots when the airplane entered the clouds during their departure.

current ice detection/protection requirements and application of technology (particularly deice boots) may not provide adequate protection for a variety of ice accumulation scenarios (tailplane, SLD, thin, rough ice accumulations, etc.). Therefore, the Safety Board believes that the FAA should actively pursue research with airframe manufacturers and other industry personnel to develop effective ice detection/protection systems that will keep critical airplane surfaces free of ice; then, require their installation on newly manufactured and in-service airplanes certificated for flight in icing conditions.

Comair's Airspeed Guidance

During postaccident interviews, some of Comair's pilot training personnel indicated that the company's EMB-120 pilot training emphasized the 160-knot minimum airspeed for operating in icing conditions, and Comair's EMB-120 Program Manager told Safety Board investigators that 170 knots is the only airspeed the company supports for operating with the landing gear and flaps retracted. Although the Safety Board's review of the airspeed guidance contained in Comair's EMB-120 FSM revealed that it did not contain specific minimum maneuvering airspeeds for flight in icing conditions and for various airplane configurations, it did contain general airspeed information in descriptions of normal and non-normal procedures and maneuvers. For example, the technique outlined in Comair's FSM for an instrument landing system (ILS) approach associated the base leg vector position (which was the accident airplane's approximate position on the approach before the upset, albeit still about 20 miles from the destination airport) with 170 knots and the flaps 15 configuration. Additional guidance for the ILS approach procedure associated 150 knots airspeed with the selection of 25° of flaps. (This guidance did not constitute minimum airspeed guidance, but it did represent how Comair intended the airplane to be flown and configured on an ILS approach.)

Comair's EMB-120 airspeed reference cards (readily available and used by the flightcrew in the cockpit) addressed a reference airspeed at an airplane gross weight of 24,000 pounds with gear and flaps retracted (V_{ref0}) of 147 knots, and a final segment airspeed (V_f)¹⁶ of 143 knots (airspeeds varied, depending on the airplane's gross landing weight and temperatures). Comair's EMB-120 FSM addressed V_{ref0} and V_f airspeeds consistent with the cockpit airspeed reference cards. The FSM also contained guidance for a no-flaps approach and landing (a non-normal procedure) that specified a minimum airspeed of 160 knots while maneuvering on the approach, with a slight airspeed reduction (the amount varying with the weight of the airplane) once established on final approach. Further, the flap control fault (a non-normal procedure) checklist procedure advised pilots to add 35 knots to the reference airspeed for 45° of flaps for the zero flaps configuration, resulting in airspeeds between 140 and 150 knots (again depending on the airplane's gross weight). The published stall airspeed for the EMB-120 at 24,000 pounds gross weight with landing gear and flaps retracted was 114 knots.

During the 13 months before the accident, Comair had issued an interoffice memorandum and an FSB that contained guidance advising EMB-120 pilots to maintain higher airspeeds than

¹⁶ V_f is the target airspeed for flap retraction after takeoff or during go-around.

normal when operating in icing conditions. The Comair interoffice memo, issued on December 8, 1995, advised pilots not to operate the EMB-120 at less than 160 knots in icing conditions and to use 170 knots for holding in icing conditions. According to Comair, this memo was distributed to all EMB-120 pilots through their company mailboxes and a 30-day pilot-read binder but was not incorporated into an FSB or a revision to the Comair EMB-120 FSM. The FSB, issued on October 18, 1996 (to be inserted at the back of the FSM), advised pilots to maintain a minimum airspeed of 170 knots when climbing on autopilot or holding in icing conditions, with no mention of a minimum airspeed for non-climbing/non-holding icing operations. Comair's October 1996 FSB did not support or repeat the interoffice memo's blanket 160-knot minimum airspeed for operating an EMB-120 in icing conditions. The Safety Board notes that the language used, the different airspeeds and criteria contained in the guidance, Comair's methods of distribution, and the company's failure to incorporate the guidance as a formal, permanent revision to the FSM might have caused pilots to be uncertain of the appropriate airspeeds for their circumstances.

Additional preaccident airspeed guidance was contained on the same page as revision 43 to Embraer's EMB-120 AFM (issued in April 1996), which stated that the manufacturer's recommended minimum airspeed for the EMB-120 in icing conditions with landing gear and flaps retracted was 160 knots. However, at the time of the accident, Comair had not incorporated the AFM revision 43 information into its EMB-120 FSM. Further, Comair had not incorporated long-standing AFM information into its FAA-approved EMB-120 FSM; specifically, Comair's FSM did not contain the note advising pilots to increase their approach airspeeds by 5 to 10 knots in icing conditions. (The Safety Board notes that this guidance had been included in Embraer's EMB-120 AFM at least since August 1991, and Comair's FAA POI had not required the company to incorporate the icing-related airspeed guidance into its FSM.) Because Comair's pilots used the company's Operations Manual and FSM as their primary sources of procedural guidance (rather than the EMB-120 AFM), it is likely that many Comair pilots were not aware that Embraer considered 160 knots to be the minimum airspeed for operating the EMB-120 in icing conditions. This is supported by the variations in the responses provided during postaccident interviews by the 16 Comair EMB-120 pilots (including line pilots, flight instructors, and line check airmen) when they were asked about the minimum airspeed for operating the EMB-120 without flaps extended in icing conditions.

Several of the pilots interviewed stated that they would not have been comfortable operating an EMB-120 in icing conditions at an airspeed of 150 knots without flaps extended, citing 160 knots or 170 knots as more acceptable airspeeds, based on previous bulletins and memos.¹⁷ Other pilots indicated that there was no operational requirement to maintain a higher airspeed in icing conditions but cited a note in Comair's FSM that advised pilots to increase approach airspeeds by 5 to 10 knots when operating in icing conditions. However, three Comair EMB-120 pilots made no special reference to icing conditions and told investigators that the minimum operating airspeed for the EMB-120 flaps up was below 150 knots. One Comair EMB-120 captain stated that he considered the absolute minimum airspeed for operating the airplane

¹⁷ Although many of Comair's line pilots, flight instructors, and line check airmen appeared uncertain of the minimum airspeed for operating an EMB-120 in icing conditions without landing gear or flaps extended, most of the pilots interviewed were aware that Comair's FSB 96-04 stated that the minimum airspeed for holding in icing conditions was 170 knots.

without flaps [in nonicing conditions] to be the V_{fs} airspeed; a Comair EMB-120 flight instructor cited a minimum EMB-120 maneuvering airspeed without flaps of 140 knots; and an EMB-120 line check airman stated that "the airplane should fly safely at 150 knots clean, but this is not a practice [we] advocate.... V_{fs} (141 knots to 147 knots), those are the minimum clean speeds."

Thus, although Comair's pilot training personnel indicated that the company's EMB-120 pilot training emphasized the 160-knot minimum airspeed for operating in icing conditions, the varied responses received from EMB-120 pilots during postaccident interviews indicate that the guidance provided was not consistently understood by Comair's pilots. Based on the inconsistencies in the answers provided by Comair pilots during the postaccident interviews and the complex and varied minimum airspeed requirements established by Comair for both icing and nonicing conditions, the Safety Board concludes that the guidance provided by Comair in its memos, bulletins, manuals, and training program did not adequately communicate or emphasize specific minimum airspeeds for operating the EMB-120 in the flaps-up configuration, in or out of icing conditions, and thus contributed to the accident.

Flightcrew's Airspeed/Configuration Decisions and Actions

The Safety Board's review of the flightcrew's actions revealed that there was no pilot discussion of flap usage, stall speeds, recommended minimum airspeeds for icing conditions, ice accumulation (potential or observed) and its effects on the airplane's performance at any time during the descent from cruise altitude, nor was there any requirement for such discussion. The Safety Board considers it likely that the pilots would have commented and/or taken action (such as activating the deicing boots and/or extending the flaps) if they had perceived an unsafe condition, either as the result of a significant ice accumulation or an unsafe airspeed assignment for the airplane's configuration. The Safety Board acknowledges that increasing the airspeed by some increment ($V_{ref} + 5$ knots according to Comair's EMB-120 FSM) when ice accretion is observed is a fairly standard adjustment in the aviation industry, and Comair's FSB 96-04 specified a minimum airspeed of 170 knots for holding in icing conditions. However, ATC had not issued holding instructions to the pilots of Comair flight 3272, nor had ATC indicated that the pilots should expect to receive holding instructions during the approach to DTW. Therefore, the pilots might not have considered the 170-knot minimum airspeed for holding in icing conditions. Additionally, as previously discussed, the pilots might not have recognized that they were operating in icing conditions because it is possible that the accident airplane accreted a thin, rough layer of glaze ice that was imperceptible to the pilots. Because there were no comments recorded by the CVR and because the pilots accepted the 150-knot airspeed assignment without hesitation, comment, or reconfiguration, the Safety Board concludes that the pilots likely did not recognize the need to abide by special restrictions on airspeeds that were established for icing conditions because they did not perceive the significance (or presence) of Comair flight 3272's ice accumulation. Further, based on the uncertainty regarding minimum airspeeds exhibited by Comair pilots during postaccident interviews, the Safety Board considers it likely that under conditions similar to those encountered by the pilots of Comair flight 3272, other Comair pilots might have accepted the same 150-knot airspeed assignment.

Although the Safety Board considers Comair's airspeed guidance ambiguous and unclear and acknowledges that the flightcrew might not have perceived that the airplane was accumulating ice that affected its flight handling characteristics, the Safety Board notes that the preponderance of the airspeed guidance available to the pilots indicated that EMB-120 operating airspeeds of 160 or 170 knots were standard for operating without flaps extended under any (icing or nonicing) conditions. Although these airspeeds were not established minimum airspeeds, they were the operator's procedural guidance and the standards to which Comair's pilots were trained. The Safety Board considers that any pilot deviations from standard procedures during flight operations (although not prohibited and not necessarily unsafe) should be accomplished thoughtfully and with full consideration given to the possible risks involved. In this case, operating at 150 knots provided the pilots with a reduced safety margin above the airplane's stall speed. The reduction in stall margin was especially critical to the accident flight because the accident airplane had accreted structural ice during its descent, which was having an adverse effect on the airplane's performance characteristics. The Safety Board notes that the pilots could have increased the stall margin by extending 15° of flaps and still complied with ATC's airspeed assignment. Further, there was no safety or operational reason to avoid extending the flaps.¹⁸

The Safety Board considers it critical that pilots take into consideration potential adverse conditions, and make correspondingly conservative decisions where they are warranted. Although the pilots might not have perceived that the airplane was accumulating any ice, their activation of the propeller and windshield heat when the airplane entered icing conditions was an indication that they were aware that they were entering conditions in which ice accumulation was possible.

Based on Comair's guidance for an ILS approach (which Comair uses during pilot training) that associates 170 knots with 15° of flaps on the base leg position, and additional airspeed guidance suggesting airspeeds of 160 to 170 knots for the accident flight's conditions, and the pilots' responsibility to make safe, conservative decisions consistent with flight in icing conditions, the Safety Board concludes that whether the pilots perceived ice accumulating on the airplane or not, they should have recognized that operating in icing conditions at the ATC-assigned airspeed of 150 knots with flaps retracted could result in an unsafe flight situation; therefore, their acceptance of the 150-knot airspeed assignment in icing conditions without extending flaps contributed to the accident.

¹⁸ The Safety Board considered the possibility that the flightcrew avoided extending the flaps because of guidance to avoid extended operations in icing conditions with flaps extended. However, as previously discussed, there were numerous indications that the flightcrew was not considering icing as a significant factor in the airplane's operation at the time. The Safety Board also considered that the pilots might have believed that they had already extended the flaps to 15° at the time that they accepted the 150 knot ATC-assigned airspeed. However, at that time, the airplane was about 20 miles from the destination airport and maintaining an assigned airspeed of 190 knots; thus, the pilots had not received any of the usual (distance and airspeed-related) cues to extend the flaps. The Safety Board was unable to determine whether the pilots believed they had extended the flaps at any subsequent time.

FAA-related Information Regarding Minimum Airspeeds

Because the issue of safe minimum airspeeds is complex and critical to safe flight operations, in May 1997 the Safety Board issued Safety Recommendation A-97-31, which asked the FAA to require air carriers to reflect FAA-approved minimum airspeeds for all flap settings and phases of flight, including flight in icing conditions, in their EMB-120 operating manuals. The Safety Board's recommendation letter referenced the FAA's notice of proposed rulemaking (NPRM) 97-NM-46-AD, which established a minimum safe EMB-120 airspeed in icing conditions of 160 knots based on initial icing certification flight test data, stating the following, in part:

The NPRM addresses many of the safety issues discussed in this letter. The Safety Board is evaluating whether the proposed 160 KIAS [knots indicated airspeed] minimum airspeed in icing conditions is appropriate, and if the single speed adequately addresses the intent of what would have been our first recommendation: that is, for the FAA to approve for inclusion in Embraer's EMB-120 airplane flight manual minimum airspeeds for all flap settings and phases of flight, including flight in icing conditions.

The Safety Board reiterated its concerns on this subject in its response to the FAA's NPRM 97-NM-46-AD. Despite the Board's concerns, the FAA's final rulemaking for airworthiness directive (AD) 97-26-06 indicated that Embraer's initial icing certification flight tests demonstrated that a minimum airspeed of 160 knots provided an adequate stall margin, "provided the ice protection systems are properly activated." Currently, the FAA-required minimum EMB-120 airspeed guidance consists of 160 knots minimum airspeed for operating in icing conditions.

AD 97-26-06 did not satisfactorily address the concerns that were expressed by the Safety Board in its communications regarding Safety Recommendation A-97-31 and in its response to the NPRM because the 160-knot airspeed was not scientifically determined and does not ensure an acceptable safety margin for all foreseeable flight conditions (evidence of Comair flight 3272's loss of control were apparent at 156 knots—with a slightly different ice accumulation scenario, the loss of control might have occurred earlier in the event) and because the FAA's response did not adequately address the complicated issue of the minimum operating airspeeds (at various flap settings) for the EMB-120 in icing conditions. The Safety Board notes that after this accident, because Comair management did not believe that a 160-knot airspeed ensured adequate stall margin, the company established a minimum airspeed of 170 knots for operating the EMB-120 in icing conditions, thus increasing the stall margin in icing conditions beyond that required by the FAA. The Safety Board is concerned that absent the scientifically determined airspeed guidance it requested from the FAA, some operators are arbitrarily electing to increase their minimum EMB-120 airspeeds, whereas others may continue to follow current FAA guidance that provides an inadequate safety margin. Although an airspeed greater than 160 knots should be required to provide an adequate safety margin, without a scientifically based determination of minimum operating airspeed in icing conditions, some operators may increase the airspeed too much, increasing the risk of tailplane stall.

The Safety Board is aware that manufacturers and operators of many large air transport airplanes have published minimum airspeeds associated with various flap configurations and phases and conditions of flight. These airspeeds are incorporated into operator's manuals and pilot training programs and are helpful for pilots of these airplanes during flight operations. The Safety Board again concludes that minimum airspeed information for various flap configurations and phases and conditions of flight would be helpful to pilots of all passenger-carrying airplanes. Therefore, the Safety Board believes that the FAA should require manufacturers of all turbine-engine driven airplanes (including the EMB-120) to provide minimum maneuvering airspeed information for all airplane configurations, phases, and conditions of flight (icing and nonicing conditions); minimum airspeeds also should take into consideration the effects of various types, amounts, and locations of ice accumulation, including thin amounts of very rough ice, ice accumulated in SLD icing conditions, and tailplane icing.

The circumstances of the Westair incident indicate that despite the increased availability of icing-related information since the Comair accident, the increase in icing-related regulations and the heightened awareness of the hazards of structural icing among the operator/pilot population that has resulted from recent icing-related aviation accidents, some EMB-120 pilots remain less vigilant to decreases in airspeed than is prudent. Although EMB-120 pilots have more icing-related information available to them now than they did before the Comair flight 3272 accident, adequate guidance has still not been provided on minimum operating airspeeds and the hazards of various types and amounts (sometimes imperceptible) of ice accumulation. Therefore, the Safety Board believes that the FAA should require the operators of all turbine-engine driven airplanes (including the EMB-120) to incorporate the manufacturer's minimum maneuvering airspeeds for various airplane configurations and phases and conditions of flight in their operating manuals and pilot training programs in a clear and concise manner, with emphasis on maintaining minimum safe airspeeds while operating in icing conditions.

Stall Warning/Protection System

The stall warning systems that are required by 14 CFR Part 25 are intended to provide flightcrews with adequate warning of proximity to the stall AOA; however, they often do not provide adequate warning when the airplane is operating in icing conditions in which the stall AOA is markedly reduced. This was the case in this accident; the airplane had departed from controlled flight before activation of the stick shaker.

The accident airplane's stall warning/protection system used information from the sideslip sensor and the right and left AOA sensors to determine an approaching aerodynamic stall condition. Under normal conditions, with uncontaminated airfoils and the airplane operating with the landing gear and flaps retracted, EMB-120 stick shaker activation would occur at 10° and the AOA at which the airplane actually stalled would be 18° , providing a margin of about 8° . However, with the wings contaminated, the airflow over the upper wing surface is disrupted, the stall airspeed is increased, and the stall AOA is reduced,¹⁹ thus decreasing the margin between

¹⁹ FAA and NASA wind/icing tunnel data indicate that the NACA 23012 airfoil with a thin layer of rough ice on the leading edge with a small ice ridge can stall at angles of attack as low as 5° or 6° .

stall warning and actual stall. The decreased margin can result in a contaminated airplane stalling with little or no prestall warning (i.e., the stick shaker) provided to the pilots and at a higher airspeed and lower AOA than a pilot might expect. Further, if a pilot was confident that the airplane's stall warning/protection system would provide an adequate stall warning margin, that pilot may not be overly concerned about the flight conditions at that time.

The Safety Board notes that the stall warning system installed on the Avions de Transport Regional (ATR) 42/72 decreases the critical AOA for aural alert and stick shaker from 12.5° to 7.5° when the anti-icing system is activated. The 7.5° AOA threshold was selected by ATR to account for a reduced stall AOA with an ice accumulation. In addition, the Safety Board is aware that stall warning/protection systems exist that incorporate airflow sensors into their logic and adjust the stick shaker/pusher activation to compensate for the disruptions in airflow that result from ice accumulation on the airfoil.

Because the accident airplane's FDR and CVR data indicated that the autopilot disengaged and the roll upset occurred before the stick shaker activated, the Safety Board concludes that the stall warning system installed in the accident airplane did not provide an adequate warning to the pilots because ice contamination was present on the airplane's airfoils and the system was not designed to account for aerodynamic degradation or adjust its warning to compensate for the reduced stall warning margin caused by the ice. Thus, the Safety Board believes that the FAA should require the manufacturers and operators of all airplanes that are certificated to operate in icing conditions to install stall warning/protection systems that provide a cockpit warning (aural warning and/or stick shaker) before the onset of stall when the airplane is operating in icing conditions.

Operation of the Autopilot

The Safety Board was unable to positively determine whether the autopilot was operating properly based on physical evidence (impact damage precluded functional tests). However, based on FDR data and a review of the autopilot design characteristics, the Safety Board concludes that the accident airplane's autopilot was capable of normal operation and appeared to be operating normally during the last minutes of the accident flight, and the autopilot disconnect and warning systems operated in a manner consistent with their design logic.

The Safety Board evaluated the flightcrew's use of the autopilot as it affected the cues presented to the pilots about the impending loss of control and the behavior of the ailerons as the loss of control developed. The autopilot's actions during the last seconds before it disengaged provided some visual cues that could have warned the pilots of the airplane's performance degradation. For example, during the 15 seconds before the autopilot disengaged, it moved the control wheel to command the ailerons to move in a RWD direction while the flight instruments and the pilots' heading selection indicated that the airplane was in a left bank. Although it would have been possible for the pilots to observe this and deduce that an anomalous flight condition existed, these visual cues began very gradually and were subtle and short lived. The control wheel did not move more than 10° , and the roll angle did not exceed 30° (only slightly greater than the normal autopilot bank limit for the selected left turn), until about 8 seconds before the upset.

The deviations from the desired airplane attitude were becoming noticeable about the time that the pilots were increasing engine power to maintain 150 knots and continued as the captain directed the first officer's attention to the airplane's airspeed (about 5 seconds before the upset). Given this distraction, it is likely that the subtle visual cues that were available were not adequate to prompt the pilots to take the direct and aggressive action that would have been necessary to avoid the upset.

If at least one of the pilots had been manually monitoring the airplane's (autopilot's) performance by maintaining a light grip on the control wheel, it is more likely that the autopilot-commanded right control wheel application (control wheel movement in the opposite direction to the turn) would have been noticed at some point before the autopilot disengaged. However, the pilots could not have identified the buildup in control wheel forces that would have preceded and accompanied the RWD control wheel movements unless the autopilot had been disengaged and they were flying the airplane manually.

Postaccident simulator tests indicated that throughout most of the airplane's left roll, even up to the time the autopilot disengaged, the pilots could have prevented the loss of control of the airplane by decreasing the AOA. However, when the autopilot suddenly disengaged, the release of the autopilot's RWD control input allowed the ailerons to move rapidly in the left wing down direction, which caused the airplane to immediately roll to a nearly inverted attitude.

The sudden disengagement of the autopilot with no warning to the flightcrew is an essential difference between the Comair flight 3272 accident and the Westair flight 7233 incident (other differences include the following: according to their statements, the Westair pilots had activated the leading edge deicing boots, and the Westair airplane's airspeed was below its target airspeed for about 3½ minutes, whereas Comair's airspeed was below the target airspeed for 10 seconds). The Westair pilots intentionally disengaged the autopilot and resumed flying the airplane manually when they felt the airplane shudder or rumble, before an unusual attitude developed. Although the Westair pilots subsequently experienced several roll oscillations and deviated 600 feet below their assigned altitude before they extended 15° of flaps, they were able to regain control of the airplane. Comair flight 3272's autopilot automatically disengaged, and, because of the left roll tendency, the airplane rolled left to a nearly inverted attitude almost immediately after the autopilot disengaged—before the pilots had their hands on the controls. The Westair airplane remained moderately more controllable because the pilots had their hands on the control wheel and were manually flying the airplane as soon as the autopilot was disengaged; further, the excessive roll oscillations did not begin until about 4 seconds after the autopilot disengaged. It is likely that the Comair flight 3272 upset event would have been more controllable if the Comair pilots had recognized the airplane's degraded aerodynamic condition and disengaged the autopilot to fly the airplane manually before the autopilot disengaged automatically and unexpectedly. The Safety Board concludes that, had the pilots been flying the airplane manually (without the autopilot engaged), they likely would have noted the increased RWD control wheel force needed to maintain the desired left bank, become aware of the airplane's altered performance characteristics, and increased their airspeed or otherwise altered their flight situation to avoid the loss of control.

After the ATR-72 accident near Roselawn, Indiana, the Safety Board issued Urgent Safety Recommendation A-94-184 to the FAA recommending, in part, that it prohibit ATR-42/72 pilots from using the autopilot in icing conditions because of the autopilot's ability to mask the airplane's changing flight condition. The FAA's response prohibited ATR 42/72 pilots from using the autopilot in icing conditions unless specific modifications were accomplished or alternative procedures and training were adopted, and the Safety Board reclassified Safety Recommendation A-94-184 "Closed—Acceptable Action." Further, based on the FAA's AD 96-09-24, in the summer of 1996, Comair revised its manuals (based on Embraer changes) to indicate that because "the autopilot may mask cues that indicate adverse changes in handling characteristics, use of the autopilot is prohibited" in SLD icing conditions.

However, the circumstances of the Comair accident demonstrate that restricting use of the autopilot only when the airplane is operating in SLD icing conditions may not be adequate. Moreover, an airplane may encounter a hazardous flight condition from use of the autopilot in icing conditions that may not be perceptible to the flightcrew. Case histories indicate that relying on pilots to activate deicing boot systems or maintain minimum airspeeds in icing conditions does not ensure safe operation of an airplane in icing conditions; pilots may not always be attentive enough to airspeeds, they may not recognize the onset of ice accumulation to trigger deicing boot activation, or deicing boot activation may not be sufficient to prevent icing-related flight control anomalies in some conditions because of intercycle icing. However, if the pilots of Comair flight 3272 had intentionally disengaged the autopilot upon the onset of ice accretion, the autopilot would not have masked the tactile cues to the airplane's aerodynamic degradation, nor would the autopilot have automatically disengaged at a subsequent, more critical time. Thus, the pilots would not have initiated their recovery from an extremely unusual attitude.

The Safety Board considered whether operation of the autopilot in the "[½ bank] angle" mode, as recommended in the "Descent/Holding/Landing" section of Embraer's OB No. 120-002/96, "Operation in Icing Conditions," might provide an adequate level of safety for use of the autopilot during maneuvering flight in icing conditions. The Safety Board notes that the sideslip and severe asymmetric degradation of the accident airplane appeared not to have begun (based on FDR data) until the airplane reached 20° of left bank (at 1554:10). However, the Safety Board also notes that the autopilot's ½ bank angle mode only applies to the lateral control mode in which it is selected—when the autopilot lateral control mode changes during flight (either pilot-commanded, or pilot preselected, such as during the transition from heading mode to approach mode), the autopilot reverts to commanding standard bank angles. Thus, the pilot would need to reengage the ½ bank angle mode in the new lateral control mode, if ½ bank angle mode is desired. This would result in an increased pilot workload during the approach phase of flight (already a high workload phase of flight) or the task (reengaging ½ bank angle mode) might not be accomplished. Thus, the Safety Board considers it unlikely that the use of the autopilot's ½ bank angle mode while operating in icing conditions (as recommended in Embraer's OB 120-002/96) would ensure an adequate level of safety to EMB-120 pilots operating in conditions conducive to the formation of structural ice.

Therefore, the Safety Board concludes that disengagement of the autopilot during all operations in icing conditions is necessary to enable pilots to sense the aerodynamic effects of icing and enhance their ability to retain control of the airplane. Because there is no reason to

believe that these circumstances may be confined to the ATR-72 and the EMB-120, the Safety Board believes that the FAA should require all operators of turbopropeller-driven air carrier airplanes to require pilots to disengage the autopilot and fly the airplane manually when they activate the anti-ice systems.

Further, based on this accident and other air carrier incidents (such as the Evergreen International B-747), the Safety Board has considered the feasibility and value of a cockpit warning when an airplane first exceeds the autopilot's maximum bank and/or pitch command limits to alert pilots to an anomalous situation. According to AlliedSignal personnel, it is possible to adjust their recent model ground proximity warning systems (GPWS) to provide a cockpit bank angle warning when the airplane's bank angle exceeds the autopilot's normal command limit with the autopilot activated. The Safety Board concludes that if the pilots of Comair flight 3272 had received a GPWS, autopilot, or other system-generated cockpit warning when the airplane first exceeded the autopilot's maximum bank command limits with the autopilot activated, they might have been able to avoid the unusual attitude condition that resulted from the autopilot's sudden disengagement. Therefore, the Safety Board believes that the FAA should require all manufacturers of transport-category airplanes to incorporate logic into all new and existing transport-category airplanes that have autopilots installed to provide a cockpit aural warning to alert pilots when the airplane's bank and/or pitch exceeds the autopilot's maximum bank and/or pitch command limits.

FAA Continuing Airworthiness Oversight Issues

The Safety Board notes that, like the ATR-42 and -72, the EMB-120 exhibited a history of icing-related upsets/losses of control before being involved in a related fatal accident. At the time of the Comair accident, six icing-related EMB-120 events had been documented, the first of which occurred in June 1989.²⁰ The Safety Board's review of these incidents shows that before the Comair accident, the EMB-120 fleet had experienced repeated instances of roll upsets associated with ice accumulations that the pilots either did not observe or did not consider sufficient to prompt activation of the deicing boots.

FAA and Embraer personnel had noted the recurring events, and the FAA presented a summary of the six events at an FAA/industry meeting (attended by Safety Board staff) on November 7, 1995. Further, the FAA and Embraer discussed the events with representatives from Comair and other operators at a meeting on November 15, 1995, and additional discussion took place during the EMB-120 SLD icing tanker tests in December 1995. An FAA engineer reviewed these six incidents in a draft report dated January 26, 1996.

The Safety Board has been unable to obtain information about the specific disposition of the draft report within the FAA, although the FAA asserted after the accident that this report did not reflect the official views of the FAA. Nevertheless, the Safety Board notes that more than

²⁰ Similarly, before the ATR-72 accident at Roselawn, Indiana, the FAA had been aware of a number of prior ATR upset events. The FAA had concluded that these incidents were essentially pilot-induced stall events; however, further investigation revealed that there were more complex airplane controllability issues involved in the ATR upset events.

1 year before the accident, at least some members of the FAA certification staff responsible for handling EMB-120 icing issues were concerned about, and were considering recommendations on, the following issues: 1) the airplane's roll behavior with ice accretion, 2) high drag from ice accretions that are not considered by the flightcrew to warrant activating the deicing boots, 3) inadequate stall warning in icing conditions, 4) inadequate stall margin with the airspeed established for use in icing conditions, and 5) problems stemming from the use of the autopilot in these conditions.

The FAA's official response to the six preaccident EMB-120 icing-related events, as expressed to the Safety Board by aircraft certification office (ACO) personnel, was that these incidents shared a common factor—flightcrew failure to activate the leading edge deicing boots. The FAA apparently believed that the EMB-120 was safe to operate in icing conditions as long as the boots were operated.

Hence, the FAA's primary action regarding EMB-120 icing before the accident was to approve the Embraer-proposed, CTA-approved revision to the AFM that pilots activate the boots at the first indication of ice accumulation (revision 43). In doing so, the FAA ACO apparently did not accept the draft report's conclusions, which recognized that pilots would not activate the boots if they did not recognize ice accumulation, that an engaged autopilot masked the tactile cues of icing, and that under these conditions, the flightcrew also could be deprived of an adequate stall warning.

The Safety Board notes with disappointment that this was the latest in a series of limited actions taken by the FAA to address the problems of structural icing in transport airplane certification and operation. Basic knowledge about the aerodynamics of icing (including the knowledge regarding the hazards of small amounts of surface roughness/ice) has been well established for the past 50 years, and there is nothing that has been learned in the most recent, postaccident wind tunnel tests and analyses that could not have been learned before this Comair accident.

Many of the concerns raised about icing in this investigation were previously identified by the Safety Board as early as its September 1981 study on icing avoidance and protection. The study raised concerns about the adequacy of the Part 25 appendix C envelope and icing certification and the difficulties in defining and forecasting icing conditions; as a result of the study, the Safety Board recommended, in part, that the FAA evaluate individual aircraft performance in icing conditions and establish operational limits, review icing criteria in Part 25 and expand (adjust) the Part 25 appendix C envelope as necessary, and establish standardized procedures for icing certification. For many years, the FAA did not respond positively to the Safety Board's recommendations, indicating that icing was not a significant problem for airplanes certificated under Part 25 appendix C. However, subsequent icing-related accidents at Pasco, Washington (in December 1989), and Beckley, West Virginia (in January 1991), revealed that flight control anomalies could result from tailplane icing and an icing-related accident at Cleveland, Ohio (in February 1991), revealed that slightly rough ice accumulations on the wing

upper surface can result in hazardous flight handling characteristics.²¹ Further, the October 1994 ATR-72 accident at Roselawn, Indiana, demonstrated that icing outside the Part 25 appendix C envelope could be a significant problem for airplanes certificated to operate in icing conditions.

After this series of fatal accidents (all of which involved icing in transport airplanes operated in air carrier service) drew attention to icing-related hazards, the FAA reacted incrementally to tailplane icing, then rough ice accumulations on the upper wing, and then, later, to runback icing (SLD). The Safety Board recognizes that following the Comair flight 3272 accident, the FAA began an important icing-related research program with Embraer and the UIUC. This work has resulted in findings about the effects of thin/rough ice accretions and ice ridges on boots, with other possible factors (such as intercycle icing and residual ice on boots) as yet unknown or unresolved. However, had the FAA adequately responded to the Safety Board's 1981 icing recommendation, the earlier accidents, or the concerns expressed in its own staff's draft report on the EMB-120 and conducted a thorough program of icing-related research that defined a course of action to prevent similar incidents by addressing the certification and operational issues (autopilot use in icing conditions, no autopilot bank angle exceedence warning, no stall warning/protection system adjustment for icing conditions, the effects of thin, rough ice and SLD accretions, etc.), this accident would likely have been avoided.

The Safety Board notes that the failure of the FAA to promptly and systematically address these certification and operational issues resulted in the pilots of Comair flight 3272 being in a situation in which they lacked sufficient tools (autopilot bank angle warning, adjusted stall warning/protection system, ice detection system, adequate deice procedures) and information (airspeed guidance, hazards of thin rough ice accretions, and absence of ice bridging) to operate safely. The Safety Board concludes that despite the accumulated lessons of several major accidents and (in the case of the EMB-120) the specific findings of a staff engineer, the FAA failed to adopt a systematic and proactive (rather than incremental and reactive) approach to the certification and operational issues of turbopropeller-driven transport airplane icing, which was causal to this accident.

Icing Certification Requirements

The Safety Board reviewed EMB-120 test data from the original certification of the airplane for flight in icing conditions (U.S. and Canadian tests) and the subsequent SLD icing certification tests, which were conducted in 1995 as a result of the ATR-72 accident near Roselawn, Indiana. The Safety Board found no evidence that the EMB-120 did not satisfy the tests to which it was subjected; in fact, during these tests, Embraer demonstrated the airplane's flight handling qualities under conditions that exceeded the boundaries of the Part 25 appendix C envelope in terms of LWC.

²¹ There have been five DC-9 series 10 airplane takeoff accidents attributed to upper wing ice contamination in the United States since 1968. Although these accidents involved turbojet-driven airplanes (not turbopropeller-driven airplanes, like the other icing-related incidents/accidents discussed in this report), the issue of the FAA's failure to address icing-related operational and certification issues is pertinent to all airplanes certificated for flight in icing conditions.

Despite the apparent fulfillment of all icing certification requirements by the EMB-120, Comair flight 3272 crashed after apparently accreting a thin layer of rough, "sandpaper-type" ice, in icing conditions that likely fell mostly within the boundaries of Part 25 appendix C, although droplets as large as 400 microns might have been present.

Consequently, the Safety Board reviewed the adequacy of the current FAA requirements for the certification of airplanes for flight in icing conditions. For an airplane to be certificated for flight in icing conditions, the FAA requires the manufacturer to demonstrate a limited number of test data points within the Part 25 appendix C envelope. The FAA's icing certification requirements are based on fully functioning and operating anti-icing and deicing systems. Although there is no requirement for manufacturers to consider the effects of delayed activation of ice protection systems, intercycle or residual ice accumulations, or other variables that might result in significant aerodynamic effects, Embraer exceeded the minimum FAA requirements when Embraer tested the EMB-120 with $\frac{3}{4}$ -inch (U.S.) and 1-inch (Canada) ice accretions/shapes during initial icing certification.²² Certification records indicate that the EMB-120 successfully exhibited satisfactory flight handling characteristics with 3-inch ram's horn ice shapes installed on unprotected surfaces. Further, during the SLD icing controllability tests, the FAA tested the EMB-120 with quarter-round artificial ice shapes as large as 1 inch located at the aft edge of the farthest aft inflatable deicing boot segment (to represent ice accumulated in icing conditions that fall outside the Part 25 appendix C envelope). The airplane exhibited full lateral controllability and satisfactory stall warning characteristics in this condition.²³

However, Embraer had not demonstrated (nor was the company required by the certification authorities to demonstrate) the EMB-120's performance in other ice configurations that would result from weather conditions within the Part 25 appendix C LWC and droplet size envelope, including realistic ice shapes (or natural ice) representing a thin layer of sandpaper-type ice with a small ice ridge (as may have been experienced by Comair flight 3272). Postaccident icing and wind tunnel information indicated that with a small ice ridge along that thin rough surface, the aerodynamic effect on handling and stall margin/stall warning (reduced stall AOA and rapid decrease in lift) can be worse than any of the ice shapes that the FAA required for icing certification.

The Safety Board's review of data from natural icing flight tests revealed that the airplane's handling characteristics were evaluated with $\frac{1}{2}$ -inch accretions on protected surfaces and that the deicing boots' ability to remove ice accretions of up to $\frac{1}{2}$ -inch was assessed.

²² For U.S. (FAA) icing certification, the EMB-120 was tested with $\frac{1}{4}$ inch, $\frac{1}{2}$ inch, and $\frac{3}{4}$ inch of natural ice on protected surfaces, up to 4 inches of natural ice accumulation on unprotected airfoil surfaces, and 3-inch ram's horn artificial ice shapes on unprotected surfaces; except for the $\frac{3}{4}$ -inch natural ice on protected surfaces, these conditions could be encountered while operating in icing conditions in accordance with procedures outlined in the EMB-120 AFM. However, for Canadian icing certification, the EMB-120 was tested with artificial ice shapes representing conditions considered to be outside normal operation with deicing boots activated (1-inch ram's horn ice shapes on protected surfaces).

²³ Although some control wheel force exceedences were observed, tanker tests identified more realistic ice shapes; during subsequent tests with the realistic ice shapes, no excessive control wheel forces or other anomalies were noted.

Embraer was not required to demonstrate the EMB-120's stall characteristics in adverse operational scenarios, including delayed boot activation, intercycle ice accretion, or residual ice on boots. As a result of the existing icing certification procedures, the FAA did not account for a thin ice accumulation (as was identified during this investigation, and which may not be observed or perceived by pilots to be a threat) that could result in a more hazardous situation than the 3-inch ram's horn shape (which is readily recognizable by pilots as a hazard and would certainly prompt activation of the boots). The Safety Board is concerned that there may be other unaccounted for ice shapes and/or accretion patterns that could result in potentially hazardous performance degradation.

The Safety Board is also concerned that the current icing certification process is overly dependent upon pilot performance; the FAA has long based its icing certification policies and practices on the assumption that pilots will perform their duties without error or misperception. FAA icing-related publications indicate that if ice formations other than those considered in the certification process are present, the airplane's airworthiness may be compromised. After an airplane is certificated by the FAA for flight in appendix C icing conditions, it becomes primarily the pilots' responsibility to ensure that the airplane is operated in icing conditions for which it was certificated. However, as noted during the investigation of the ATR-72 accident at Roselawn, during normal flight operations, pilots often cannot tell the difference between icing conditions that fall within the appendix C envelope and icing conditions outside the appendix C envelope.²⁴ (For example, a pilot cannot differentiate between 40 micron droplets and 100 micron droplets.) Because pilots often cannot determine whether icing conditions are consistent with "those considered in the certification process" (i.e., limited points within the appendix C certification envelope), or not (i.e., SLD icing conditions, or other potentially hazardous conditions that were not subjected to testing, analysis, or demonstration during icing certification work), it is virtually inevitable that the airplane will unknowingly be operated in icing conditions that fall outside the certification envelope, or in which the airplane had not demonstrated that it could operate safely.

Further, as has been recognized for 50 years or more, and demonstrated in accidents in the 1970s, 1980s, and early 1990s, and then again in the Comair flight 3272 accident, surface roughness/ice accretions that may be imperceptible or appear insignificant to pilots can adversely affect the operation of the airplane. However, because of the imperceptible or seemingly insignificant nature of those accretions, pilots who operate the airplane's deicing boots in accordance with manufacturer's guidance (that advises them to wait until a recommended thickness of ice accretes) may not activate the deicing boots under these circumstances. An article written by a Douglas Aircraft Company design engineer (published in January 1979) indicated that although most pilots are aware of the adverse aerodynamic effects of large amounts of ice, pilots appear less aware that seemingly insignificant amounts of thin, rough ice on an airfoil's leading edge can significantly degrade the airplane's flight characteristics. The deicing boot operating procedures now contained in most airplane manuals contribute to this lack of awareness by advising pilots to wait until a recommended thickness of ice accretes.

²⁴ The FAA has since required manufacturers of turbopropeller-driven airplanes to develop visual cues for SLD icing; however, the cues were based on very limited testing. Thus, the Safety Board is not convinced that such cues will exist for all icing conditions outside the appendix C icing envelope.

During the investigation of this accident, arguments were made that the pilots caused the accident because they accepted an airspeed 10 knots slower than Comair's FSM recommended for holding in icing conditions. However, the Safety Board notes that an EMB-120 loaded and configured similar to Comair flight 3272, and operated at 150 knots without any ice accretions, would have a 36-knot margin between its operating airspeed and the stall speed. This margin would likely appear to be an adequate safety margin to a pilot who did not recognize that the airplane was accumulating ice or did not believe that enough ice had accumulated to warrant activation of the deicing boots. The flight handling testing that occurred during the icing certification process did not identify that control problems that were observed in the accident airplane's performance at an airspeed of about 156 knots (only 4 knots below the 160-knot minimum speed for flight in icing conditions set by the FAA following the Comair accident) with only a small amount of ice accreted on the deicing boots. It is possible that if the FAA had required manufacturers to conduct tests with small amounts of rough-textured ice accreted on the protected surfaces (as might occur before boot activation and between boot cycles) during icing certification testing, the absence of an adequate safety margin above the stall speed would have been identified. Further, the FAA could have ensured pilot awareness of icing and adequate stall warning by requiring manufacturers to install ice detectors²⁵ and stall warning systems with reduced AOA thresholds for operations in icing conditions.

Based on its concerns that the current icing certification standards did not require testing for all realistic hazardous ice accretion scenarios, in its 1981 icing-related safety study, the Safety Board recommended that the FAA review the adequacy of the 1950s-era Part 25 appendix C icing envelope, update the procedures for aircraft icing certification, and oversee the manufacturers' evaluations of aircraft performance in various icing conditions. The circumstances of the Comair flight 3272 accident demonstrated again the continuing need for these FAA actions. The Safety Board considers the information that has been available regarding thin, rough ice accretions sufficient to have prompted the FAA to require additional testing within the appendix C envelope to demonstrate the effects of thin, rough ice as part of the icing certification process. Had the FAA required such additional testing, the resultant information regarding the stall margin and operational envelope of the EMB-120 might have been used to define minimum airspeeds for operating the airplane in icing conditions. Therefore, based on its review of the history of icing information, the icing-related incident and accident history, the EMB-120 initial icing certification data, the EMB-120 SLD icing controllability test results, and the circumstances of this accident, the Safety Board concludes that the icing certification process has been inadequate because it has not required manufacturers to demonstrate the airplane's flight handling and stall characteristics under a sufficiently realistic range of adverse ice accretion/flight handling conditions.

As a result of its investigation of the 1994 Roselawn accident, the Safety Board issued Safety Recommendations A-96-54 and A-96-56 (currently classified "Open—Acceptable Response"), which, respectively, stated that the FAA should do the following:

Revise the icing criteria published in 14 CFR Parts 23 and 25, in light of both recent research into aircraft ice accretion under varying conditions of liquid water content, drop size distribution, and temperature, and recent developments in both the design

²⁵ Rosemount ice detectors were first used in military and transport-category airplanes in the early 1970s.

and use of aircraft. Also, expand the Appendix C icing certification envelope to include freezing drizzle/freezing rain and mixed water/ice crystal conditions, as necessary.

Revise the icing certification testing regulation to ensure that airplanes are properly tested for all conditions in which they are authorized to operate, or are otherwise shown to be capable of safe flight into such conditions. If safe operations cannot be demonstrated by the manufacturer, operational limitations should be imposed to prohibit flight in such conditions and flightcrews should be provided with the means to positively determine when they are in icing conditions that exceed the limits for aircraft certification.

Further, based on a perceived depletion of the FAA's technical expertise, the 1993 U.S. General Accounting Office report entitled "Aircraft Certification: New FAA Approach Needed to Meet Challenges of Advanced Technology" recommended that the FAA should hire more technical subject matter specialists in various areas, including that of environmental icing. After the Roselawn accident, the FAA developed a three-phase, multi-pronged plan to address icing-related concerns, including operational issues, forecasting/defining icing conditions, certification issues, validating simulation methods, identifying the aerodynamic effects of accretion, and identifying visual cues to various hazardous icing conditions and (about 2 years after the Roselawn accident) hired its current Environmental Icing National Resource Specialist (NRS). In January 1998, the FAA's Environmental Icing NRS updated the Safety Board on the FAA's progress with its plan, indicating that the first two phases have been completed and progress is being made in several aspects of Phase III (specifically in the areas of understanding the effects of various ice accretions, operational issues such as bridging, and development of ice detection/protection equipment).

The Safety Board notes that the FAA's three-phase plan could potentially satisfy the need for a comprehensive review of all aspects of structural icing in turbopropeller-driven transport airplanes. However, the regulatory/certification changes addressed during Phase III have encountered delays. FAA personnel reported to the Safety Board that their attempts to produce an advisory circular (AC) that would appropriately revise methods of compliance with Parts 23/25 and Part 25 appendix C were not successful;²⁶ therefore, they changed their approach to the problem and issued two of three proposed ACs addressing changes to methods of compliance and are going through the rulemaking process for the needed regulatory changes. According to FAA personnel, ACs addressing methods of compliance with Parts 23 and 25 were issued on August 19, 1998, and March 31, 1998, respectively, and the newly created AC 25.1419 is currently in draft form, with no estimated issue date available. FAA personnel estimated that the rulemaking process will probably not be completed until January 2000.

In response to the Safety Board's Safety Recommendations A-96-54 and A-96-56, the FAA assigned aviation rulemaking advisory committee (ARAC) working groups to accomplish, in part, the following: to establish criticality of ice accretions on airplane performance and handling

²⁶ According to the FAA's Environmental Icing NRS, FAA legal personnel determined that portions of the AC appeared to require regulatory changes and therefore could not be addressed solely by means of an AC.

qualities, to develop icing certification criteria for the safe operation of airplanes in icing conditions that are not covered by the current certification envelope, and to consider the development of a regulation requiring the installation of ice detectors or equivalent means to warn flightcrews of ice accumulations. The Safety Board appreciates the efforts of the FAA Environmental Icing NRS and the ARAC working groups, and the Safety Board concludes that the work conducted by the FAA Environmental Icing NRS and the ARAC icing-related working groups is of crucial importance to the future safety of icing operations. Consequently, the Safety Board believes that the FAA should expedite the research, development, and implementation of revisions to the icing certification testing regulations to ensure that airplanes are adequately tested for the conditions in which they are certificated to operate; the research should include identification (and incorporation into icing certification requirements) of realistic ice shapes and their effects and criticality. Further, the Board reiterates Safety Recommendation A-96-54 and A-96-56 to the FAA.

The Safety Board further notes that according to the FAA's EMB-120 Aircraft Certification Program Manager and Environmental Icing NRS, the new standards, criteria, and methods of compliance contained in Parts 23 and 25 and corresponding ACs that are currently being developed would be applied only to future icing certification projects and would not be retroactively applied to airplanes currently certificated for flight in icing conditions. The Safety Board is concerned that if the FAA does not retroactively apply the revised icing certification standards and methods of compliance to airplanes currently certificated for flight in icing conditions, flight handling/controllability anomalies that have not been accounted for may remain unaccounted for until after a fatal accident, as occurred in the ATR-72 accident at Roselawn and the EMB-120 accident at Monroe, Michigan. The Safety Board concludes that the potential consequences of operating an airplane in icing conditions without first having thoroughly demonstrated adequate handling/controllability characteristics in those conditions are sufficiently severe that they warrant as thorough a certification test program as possible, including application of revised standards to airplanes currently certificated for flight in icing conditions.

Therefore, the Safety Board believes that the FAA should, when the revised icing certification standards and criteria are complete, review the icing certification of all turbopropeller-driven airplanes that are currently certificated for operation in icing conditions and perform additional testing and take action as required to ensure that these airplanes fulfill the requirements of the revised icing certification standards. Further, pending the accomplishment of these actions, the Safety Board believes that the FAA should review turbopropeller-driven airplane manufacturers' AFMs and air carrier flightcrew operating manuals (where applicable) to ensure that these manuals provide operational procedures for flight in icing conditions, including the activation of leading edge deicing boots, the use of increased airspeeds, and disengagement of autopilot systems before entering icing conditions (that is, when other anti-icing systems have traditionally been activated).

FAA Policies for Airplane Flight Manuals and Air Carrier Operating Manual Revisions

Because FAA Order 8400.10, "Air Transportation Operations Inspector's Handbook," only requires operators to maintain a flight manual that complies with existing regulations

and "safe operating procedures," Comair was not required to incorporate manufacturer-recommended procedures or revisions. In addition to the air carrier's decision not to incorporate the procedures contained in Embraer's EMB-120 AFM revision 43 into its own FSM, Comair also had not incorporated Embraer's long-standing procedures for the use of engine ignition and inlet deice boots in icing conditions. Because this investigation revealed several instances in which Comair elected not to incorporate potentially critical safety-of-flight AFM procedures into its operating manual and because the POI for Comair (although he had received a copy of AFM revision 43 from Embraer) was apparently not concerned by the operators' failure to incorporate such procedures, the Safety Board became concerned that the FAA's procedures for the management and oversight of air carriers' manuals may not be adequate.

Although it was somewhat controversial, revision 43 had been reviewed by FAA and CTA certification personnel and had been approved by these certification authorities as the proper way to operate the equipment. However, at the time of the accident, Comair and four of the other six U.S.-based EMB-120 operators had not incorporated revision 43 in their flightcrew operating manuals. This was possible, in part, because the FAA had not mandated incorporation of AFM revision 43 into operators' procedures. (Further, the FAA had not required Comair to incorporate AFM guidance advising pilots to increase approach airspeeds by 5 to 10 knots when operating in icing conditions.) In its October 1997 memo, the FAA stated that it would only issue an AD to mandate an AFM revision when it considered the change "significant enough to warrant retroactive application to all aircraft." No AD was issued when revision 43 to the EMB-120 AFM was approved; therefore, the FAA apparently did not consider the procedural changes contained in AFM revision 43 "significant enough" to require air carriers' compliance. Further, existing FAA policy does not require interaction or dialog between FAA flight standards and air carrier personnel regarding AFM procedures or revisions. Because Comair had not adopted the AFM revision 43 procedures, the pilots of flight 3272 were (unknowingly) operating in icing conditions without the most current, safest icing-related guidance. Had Comair incorporated AFM revision 43 into its EMB-120 operating procedures, the flightcrew might have activated the deicing boots before the loss of control of the airplane, possibly precluding the accident. Therefore, the Safety Board concludes that the current FAA policy allowing air carriers to elect not to adopt AFM operational procedures without clear written justification can result in air carriers using procedures that may not reflect the safest operating practices. The Safety Board believes that the FAA should require air carriers to adopt the operating procedures contained in the manufacturer's AFM and subsequent approved revisions or provide written justification that an equivalent safety level results from an alternative procedure.

Based on the history of revision 43 and the need for the FAA to more closely review and approve air carrier compliance with AFM procedures, the Safety Board assessed the capacity of the FAA flight standards organization to perform such an enhanced function. The Safety Board considers the FAA's current system inadequate because it allows for less than thorough review and communication regarding safety-of-flight data/information in a number of areas (i.e., certification, icing certification, continuing airworthiness/oversight). Before the Comair accident, the FAA POI who was responsible for oversight of Comair was not aware of the background information justifying revision 43 to the EMB-120 AFM and thus did not pursue corresponding procedural changes with Comair. According to a memo received by the Safety Board in October 1997 from FAA personnel (the Acting Director of Flight Standards Service

and the Director of Aircraft Certification Service), at the time of the accident, there was no procedure to ensure that information (including AFM changes) not mandated by an AD was shared between ACO and/or AEG personnel and other Flight Standards personnel (specifically, the POIs). The memo stated that although informal communications (described by FAA personnel as "discretionary") can occur in some cases between ACO and/or AEG personnel and POIs, there was no formal procedure to ensure that the necessary communication and coordination take place. (The memo further stated that the airplane operators "typically supply that revision to the POI.")

According to the authors of the memo, when the FAA receives an AFM revision from a manufacturer, the ACO personnel would not engage in discussions with Flight Standards personnel unless they believed that the AFM revision was particularly noteworthy, in which case they would discuss it with flight standards AEG personnel. Further, there was no explicit line of communication between the AEG and POIs. Thus, under the current system, the POI (or other pertinent flight standards personnel) might never know about the revision (if ACO personnel deemed it unnoteworthy) unless they receive a copy from the manufacturer (as was the case with Embraer's AFM revision 43) or unless an operator requests approval for an associated change to its flightcrew operating manual.

The Safety Board has observed similar communication/coordination problems between FAA offices during other investigations—specifically, during the investigation of the 1987 CASA C-212-CC accident at Romulus, Michigan, and the 1994 ATR-72 accident at Roselawn. As a result of the ATR-72 accident, the Safety Board recommended (in Safety Recommendation A-96-62) that the FAA develop an organizational structure and communications system to ensure that accident/incident information is disseminated to ensure effective continuing airworthiness oversight, with specific emphasis on the AEG. In April 1997, the FAA agreed that it would review its then-current organizational structure and processes to determine the adequacy of the communications and monitoring of the continuing airworthiness of aircraft, and the Safety Board classified the recommendation "Open—Acceptable Response." On February 25, 1998, the FAA responded that it had initiated positive improvements. Based on this action and the Board's continuing dialogue with the FAA on this issue, Safety Recommendation A-96-62 remains classified "Open—Acceptable Response."

During a June 11, 1998, meeting, FAA management personnel advised Safety Board staff that the FAA had completed the review of its internal communications procedures and had identified areas in which improvements were warranted. The Director of Aircraft Certification Services stated that the FAA is "committed to making changes, [and is] putting a team together" to establish new procedures to ensure that information is shared with all pertinent personnel in all branches of the FAA. He reported that under the new system, the ACO Project Manager and Flight Test Manager will discuss all flight manual revisions with flight standards AEG personnel, who will in turn discuss the revisions with the POIs whose operators are affected; the discussions will not hinge on a subjective determination of significance, and a dispute resolution process will be established. The Safety Board considers these improved communication procedures to be essential under both the existing FAA policy in which air carrier adoption of AFM procedures is optional, and the Safety Board's proposed policy that would in most cases mandate adoption of these procedures. Under the proposed policy, flight standards and ACO personnel would need

to coordinate the evaluation of AFM revisions and the equivalence of alternatives proposed by the air carriers.

Thus, the Safety Board concludes that at the time of the Comair flight 3272 accident, pertinent flight standards personnel (specifically, the POI assigned to Comair) lacked information critical to the continued safe operation of the EMB-120 fleet and would have been unable to evaluate the need to incorporate AFM revision 43 or any alternatives proposed by air carriers. Therefore, the Safety Board believes that the FAA should ensure that flight standards personnel at all levels (from AEGs to certificate management offices) are informed about all manufacturer OBs and AFM revisions, including the background and justification for the revision.

Westair EMB-120 FDR Sensor Information

The Safety Board has observed anomalous FDR-recorded values for flight control parameters on seven of eight Embraer EMB-120 FDRs it has reviewed, including the FDRs from the Comair and the Westair airplanes. The Westair incident occurred after the FAA established new FDR inspection/potentiometer calibration requirements for operators of EMB-120 airplanes, and Westair's maintenance records indicated that an FDR system check was conducted on the incident airplane on December 27, 1997, with no system discrepancies noted. The test procedure was conducted with the airplane stationary and the engines not running; there was no requirement for an FDR readout during the test procedure.

Although there were no sensor discrepancies noted during the Westair FDR system check, the Safety Board's postincident review of the incident airplane's FDR data revealed discrepancies in the control wheel and rudder pedal position parameters. The Safety Board's evaluation of the potentiometer calibration test criteria and the symptoms displayed by the problem sensors indicated that the sensor anomalies may not have been detectable during static tests on the ground. The test procedure did not provide an evaluation of sensor performance under normal operating conditions and, therefore, may be of limited use in detecting noisy signals or invalid signals that are confined to only a portion of the sensor's normal operating range. The Safety Board considers it likely that if an FDR readout had been conducted and pertinent parameters reviewed in conjunction with the FDR system check, the control wheel position and rudder sensor anomalies would have been observed, and efforts would have been taken to correct them.

Reliable FDR information is critical to understanding accident/incident scenarios and invaluable in identifying complex safety issues and solutions; when FDR information is not recorded (or is recorded incorrectly) for any given parameter, it becomes more likely that potentially significant safety issues will not be identified. Further (as noted in the Safety Board's report regarding the August 1997 accident involving a Fine Airlines Douglas DC-8-61 at Miami, Florida),²⁷ reliable FDR data, read out at regular inspection intervals, can be useful for purposes other than accident/incident investigation. Analysis of such FDR data could be used by operators to monitor trends and efficiency in their flight operations through a flight operations quality

²⁷ See National Transportation Safety Board. 1998. *Fine Airlines Flight 101, Douglas DC-8-61, N27UA, Miami, Florida, August 7, 1997. Aircraft Accident Report NTSB/AAR-98/02*. Washington, DC.

assurance program and could be used on an industry-wide basis to streamline flight operations, refine ATC procedures and airport configurations, and improve aircraft designs.

The Safety Board concludes that the FAA's current EMB-120 FDR system inspection procedure is inadequate because it allows existing flight control sensor anomalies to go undetected, and thus uncorrected. Therefore, the Safety Board believes that the FAA should revise its current EMB-120 FDR system inspection procedure to include an FDR readout and evaluation of parameter values from normal operations to ensure a more accurate assessment of the operating status of the flight control position sensors on board the airplane.

The Lack of Additional Icing-Related Pilot Reports

The Safety Board's investigation of the meteorological aspects of this accident revealed that about 16 icing-related pilot reports (PIREPs) were issued by pilots operating in the northwestern Ohio/southern Michigan area between 1300 and 1700 on the day of the accident. However, when the Safety Board distributed a weather conditions survey to additional flightcrews that were operating near Detroit about the time of the accident, 9 of the 11 pilots who responded to the survey reported that they encountered icing conditions. Of the nine pilots who indicated that they encountered icing conditions, only one pilot had submitted a pilot report for the conditions they observed on the day of the accident. (In response to a survey question that asked if they submitted a PIREP, two pilots stated that they did not submit a PIREP because the conditions encountered were consistent with the forecast icing conditions; one pilot reported that he did not submit a PIREP because of accident-related congestion on the ATC frequency; and the pilots of another airplane reported that they were too busy during the approach, landing, and taxi to submit a PIREP. The survey responses from the other four responding pilots did not state why they did not submit PIREPs.)

Although the Safety Board does not believe that the absence of these additional PIREPs affected the accident flightcrew's actions (because they were provided with adequate preflight, en route, and arrival weather information to conduct the flight safely; they should have been aware that they would be operating in potential icing conditions), it is possible that the PIREP information would have greatly benefited other pilots. Because PIREPs are an important and valuable source of weather information for pilots, the Safety Board is concerned that pilots had observed icing in the Detroit area the day of the accident but did not share that information with other pilots. Thus, the Safety Board concludes that the failure of pilots who encounter in-flight icing to report the information to the appropriate facility denies other pilots operating in the area the access to valuable and timely information that could prevent an accident. Therefore, the Safety Board believes that the FAA should reemphasize to pilots, on a periodic basis, their responsibility to report meteorological conditions that may adversely affect the safety of other flights, such as in-flight icing and turbulence, to the appropriate facility as soon as practicable.

Also, because a Detroit air traffic controller did not disseminate icing-related information that he had received from another flight operating in the area about 20 minutes before the accident, the Safety Board examined the dissemination of icing-related information through the ATC system. The Board notes that the Standard Operating Procedures handbook for DTW Air Traffic Control Tower and Terminal Radar Approach Control did not require that icing

reports be included on the automatic terminal information service (ATIS) recording that is monitored by all pilots. Although FAA Order 7110.65, "Air Traffic Control," contains guidance that PIREPs of any type should be included in the ATIS broadcast "as appropriate" and "pertinent to operations in the terminal area," this guidance is too broad and subjective to adequately ensure the transmission of icing-related information in an airport terminal environment. Reports of icing conditions should be of interest to all pilots operating within that environment, especially considering the normally reduced airspeeds and decreased stall margins for airplanes operating in the approach and departure phases of flight. Therefore, the Safety Board concludes that the FAA ATC system has not established adequate procedures for the dissemination of icing-related pilot reports received in the airport terminal environment; these reports should be incorporated into ATIS broadcasts so that all arriving and departing pilots can become aware of icing conditions in the area. Consequently, the Safety Board believes that the FAA should amend FAA Order 7110.65, "Air Traffic Control," to require that ATIS broadcasts include information regarding the existence of pilot reports of icing conditions in that airport terminal's environment (and adjacent airport terminal environments as meteorologically pertinent and operationally feasible) as soon as practicable after receipt of the pilot report.

Therefore, the National Transportation Safety Board makes the following recommendations to the Federal Aviation Administration:

Amend the definition of trace ice contained in Federal Aviation Administration (FAA) Order 7110.10L, "Flight Services," (and in other FAA documents as applicable) so that it does not indicate that trace icing is not hazardous. (A-98-88)

Require principal operations inspectors (POIs) to discuss the information contained in airplane flight manual revisions and/or manufacturers' operational bulletins with affected air carrier operators and, if the POI determines that the information contained in those publications is important information for flight operations, to encourage the affected air carrier operators to share that information with the pilots who are operating those airplanes. (A-98-89)

With the National Aeronautics and Space Administration and other interested aviation organizations, organize and implement an industry-wide training effort to educate manufacturers, operators, and pilots of air carrier and general aviation turbopropeller-driven airplanes regarding the hazards of thin, possibly imperceptible, rough ice accumulations, the importance of activating the leading edge deicing boots as soon as the airplane enters icing conditions (for those airplanes in which ice bridging is not a concern), and the importance of maintaining minimum airspeeds in icing conditions. (A-98-90)

Require manufacturers and operators of modern turbopropeller-driven airplanes in which ice bridging is not a concern to review and revise the guidance contained in their manuals and training programs to include updated icing information and to emphasize that leading edge deicing boots should be activated as soon as the airplane enters icing conditions. (A-98-91)

With the National Aeronautics and Space Administration and other interested aviation organizations, conduct additional research to identify realistic ice accumulations, to include intercycle and residual ice accumulations and ice accumulations on unprotected surfaces aft of the deicing boots, and to determine the effects and criticality of such ice accumulations; further, the information developed through such research should be incorporated into aircraft certification requirements and pilot training programs at all levels. (A-98-92)

Actively pursue research with airframe manufacturers and other industry personnel to develop effective ice detection/protection systems that will keep critical airplane surfaces free of ice; then require their installation on newly manufactured and in-service airplanes certificated for flight in icing conditions. (A-98-93)

Require manufacturers of all turbine-engine driven airplanes (including the EMB-120) to provide minimum maneuvering airspeed information for all airplane configurations, phases, and conditions of flight (icing and nonicing conditions); minimum airspeeds also should take into consideration the effects of various types, amounts, and locations of ice accumulation, including thin amounts of very rough ice, ice accumulated in supercooled large droplet icing conditions, and tailplane icing. (A-98-94)

Require the operators of all turbine-engine driven airplanes (including the EMB-120) to incorporate the manufacturer's minimum maneuvering airspeeds for various airplane configurations and phases and conditions of flight in their operating manuals and pilot training programs in a clear and concise manner, with emphasis on maintaining minimum safe airspeeds while operating in icing conditions. (A-98-95)

Require the manufacturers and operators of all airplanes that are certificated to operate in icing conditions to install stall warning/protection systems that provide a cockpit warning (aural warning and/or stick shaker) before the onset of stall when the airplane is operating in icing conditions. (A-98-96)

Require all operators of turbopropeller-driven air carrier airplanes to require pilots to disengage the autopilot and fly the airplane manually when they activate the anti-ice systems. (A-98-97)

Require all manufacturers of transport-category airplanes to incorporate logic into all new and existing transport-category airplanes that have autopilots installed to provide a cockpit aural warning to alert pilots when the airplane's bank and/or pitch exceeds the autopilot's maximum bank and/or pitch command limits. (A-98-98)

Expedite the research, development, and implementation of revisions to the icing certification testing regulations to ensure that airplanes are adequately tested for the conditions in which they are certificated to operate; the research should include identification (and incorporation into icing certification requirements) of realistic ice shapes and their effects and criticality. (A-98-99)

When the revised icing certification standards and criteria are complete, review the icing certification of all turbopropeller-driven airplanes that are currently certificated for operation in icing conditions and perform additional testing and take action as required to ensure that these airplanes fulfill the requirements of the revised icing certification standards. (A-98-100)

Review turbopropeller-driven airplane manufacturers' airplane flight manuals and air carrier flightcrew operating manuals (where applicable) to ensure that these manuals provide operational procedures for flight in icing conditions, including the activation of leading edge deicing boots, the use of increased airspeeds, and disengagement of autopilot systems before entering icing conditions (that is, when other anti-icing systems have traditionally been activated). (A-98-101)

Require air carriers to adopt the operating procedures contained in the manufacturer's airplane flight manual and subsequent approved revisions or provide written justification that an equivalent safety level results from an alternative procedure. (A-98-102)

Ensure that flight standards personnel at all levels (from aircraft evaluation groups to certificate management offices) are informed about all manufacturer operational bulletins and airplane flight manual revisions, including the background and justification for the revision. (A-98-103)

Revise its current EMB-120 flight data recorder (FDR) system inspection procedure to include a FDR readout and evaluation of parameter values from normal operations to ensure a more accurate assessment of the operating status of the flight control position sensors on board the airplane. (A-98-104)

Reemphasize to pilots, on a periodic basis, their responsibility to report meteorological conditions that may adversely affect the safety of other flights, such as in-flight icing and turbulence, to the appropriate facility as soon as practicable. (A-98-105)

Amend Federal Aviation Administration Order 7110.65, "Air Traffic Control," to require that automatic terminal information service broadcasts include information regarding the existence of pilot reports of icing conditions in that airport terminal's environment (and adjacent airport terminal environments as meteorologically pertinent and operationally feasible) as soon as practicable after receipt of the pilot report. (A-98-106)

In addition, the Safety Board reiterates the following safety recommendations to the Federal Aviation Administration:

Revise the icing criteria published in 14 Code of Federal Regulations Parts 23 and 25, in light of both recent research into aircraft ice accretion under varying conditions of liquid water content, drop size distribution, and temperature, and recent development in both the design and use of aircraft. Also, expand the Part 25 appendix C icing

certification envelope to include freezing drizzle/freezing rain and mixed water/ice crystal conditions, as necessary. (A-96-54)

Revise the icing certification testing regulation to ensure that airplanes are properly tested for all conditions in which they are authorized to operate, or are otherwise shown to be capable of safe flight into such conditions. If safe operations cannot be demonstrated by the manufacturer, operational limitations should be imposed to prohibit flight in such conditions and flightcrews should be provided with the means to positively determine when they are in icing conditions that exceed the limits for aircraft certification. (A-96-56)

Chairman HALL, Vice Chairman FRANCIS,** and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in these recommendations.


By: Jim Hall
Chairman

**Vice Chairman Francis did not participate in the vote to reiterate Safety Recommendations A-96-54 and A-96-56.



National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: November 30, 1998

In reply refer to: A-98-107 to -108

Honorable Daniel S. Goldin
Administrator
National Aeronautics and Space Administration
Washington, D.C. 20546

About 1554 eastern standard time,¹ on January 9, 1997, an Empresa Brasileira de Aeronautica, S/A (Embraer) EMB-120RT, N265CA, operated by COMAIR Airlines, Inc.,² as flight 3272, crashed during a rapid descent after an uncommanded roll excursion near Monroe, Michigan. Comair flight 3272 was being operated under the provisions of Title 14 Code of Federal Regulations (CFR) Part 135 as a scheduled, domestic passenger flight from the Cincinnati/Northern Kentucky International Airport (CVG), Covington, Kentucky, to Detroit Metropolitan/Wayne County Airport (DTW), Detroit, Michigan. The flight departed CVG about 1508, with 2 flightcrew members, 1 flight attendant, and 26 passengers on board. There were no survivors. The airplane was destroyed by ground impact forces and a postaccident fire. Instrument meteorological conditions prevailed at the time of the accident, and flight 3272 was operating on an instrument flight rules flight plan.

The National Transportation Safety Board determined that the probable cause of this accident was the Federal Aviation Administration's (FAA) failure to establish adequate aircraft certification standards for flight in icing conditions, the FAA's failure to ensure that a Centro Tecnico Aeroespacial/FAA-approved procedure for the accident airplane's deice system operation was implemented by U.S.-based air carriers, and the FAA's failure to require the establishment of adequate minimum airspeeds for icing conditions, which led to the loss of control when the airplane accumulated a thin, rough accretion of ice on its lifting surfaces.³

¹ Unless otherwise indicated, all times are eastern standard time, based on a 24-hour clock.

² Within this safety recommendation letter, COMAIR Airlines, Inc., will be identified as Comair.

³ National Transportation Safety Board. 1998. *In-Flight Icing Encounter and Uncontrolled Collision With Terrain, Comair Flight 3272, Embraer EMB-120RT, N265CA, Monroe, Michigan, January 9, 1997. Aircraft Accident Report NTSB/AAR-98/04.* Washington, DC.

Summary of Accident Sequence

According to cockpit voice recorder (CVR) and air traffic control (ATC) information, during the 20 minutes preceding the accident, the pilots received a series of clearances from ATC that included descent, airspeed, and heading instructions. Flight data recorder (FDR) and radar data indicated that the airplane's descent from the en route cruise altitude of flight level 210 to 4,000 feet mean sea level (msl) was stable and controlled and was accomplished at airspeeds and headings consistent with those assigned by ATC. Meteorological information and pilot reports indicated that the airplane was probably intermittently in clouds as it descended between about 11,000 feet msl and 8,200 feet msl; below 8,200 feet msl, the airplane was probably operating predominantly in the clouds.

The pilots were operating with the autopilot engaged during the descent. They had completed the descent checklist (including the activation of the propeller deicing and windshield heat at the ice protection checklist prompt) and the first four of the six items on the approach checklist⁴ before the airplane reached 4,000 feet msl during its descent. At 1553:59, when the autopilot was leveling the airplane at 4,000 feet msl on a heading of 180°, the airplane was in the clean configuration (no flaps or gear extended) at an airspeed of about 166 knots (the pilots were beginning to reduce the airspeed to the ATC-assigned airspeed of 150 knots). At that time, ATC instructed the pilots of flight 3272 to turn left to a heading of 090°. Shortly after the pilots initiated the left turn (by selecting the assigned heading for the autopilot), the airplane reached its selected altitude and (at 1554:08) the autopilot automatically transitioned to the altitude hold mode. As the autopilot attempted to maintain the selected altitude, the airplane's angle-of-attack (AOA) began to increase and the airspeed continued to decrease; at 1554:10, the autopilot began to trim the elevator (pitch trim) to an increasingly nose-up position.

The accident airplane's FDR data indicated that at 1554:10 the airplane's left bank steepened beyond 20° (moving toward the autopilot's command limit in the heading mode of 25°, +/- 2.5°). At that point (according to the autopilot design and FDR information), the roll rate exceeded that required by the autopilot's design logic to achieve the commanded roll angle, and the autopilot's input to the aileron servos moved the ailerons (and thus the airplane's control wheel) in the right-wing-down direction to counter the increasing left roll rate. FDR data indicated that, during the next 3 seconds, the left and right AOA vanes began to diverge, indicating a left sideslip/yaw condition, and the lateral acceleration values began to increase to the left while the autopilot increased the control wheel input to the right in an attempt to control the roll. Thus, by 1554:10, as the airspeed decreased through 155 knots, the airplane experienced the beginning of a significant asymmetry in the lift distribution between the right and left wings and an uncommanded yaw and roll to the left.⁵ The roll and control wheel position parameters continued

⁴ According to several Comair EMB-120 pilots, the remaining approach checklist items—flight attendants, notified and flaps, 15/15/checked—would normally be accomplished later during the approach, as the airplane neared the destination airport.

⁵ Evaluation of the FDR information revealed that a slight asymmetry of lift because of ice existed earlier in the flight; however, it became aerodynamically significant about 1554:10.

to trend in opposite directions, and the left and right AOA vanes continued to split for the next 14 seconds, until the autopilot disconnected at 1554:24.125.

Just after 1554:15, as the airplane's airspeed began to decrease below 150 knots, the pilots began to increase the engine power;⁶ however, the airplane's airspeed continued to decrease. When the captain drew the first officer's attention to the low airspeed indication at 1554:20.8, the airplane's airspeed had decreased to 147 knots. During the next 2 seconds, the pilots more aggressively increased the engine power, and a significant torque split occurred; the torque values peaked at 108 percent on the left engine and 138 percent on the right engine. The Safety Board considered several possible reasons for the significant torque split, including uneven throttle movement by the pilots, ice ingestion by the left engine, a misrigged engine, or an improper engine trim adjustment on the newly installed right engine; however, it was not possible to positively determine the cause of the torque split. Postaccident simulations indicated that this torque split had a significant yaw-producing effect at a critical time in the upset event, exacerbating the airplane's excessive left roll tendency. The airplane's airspeed decreased further to 146 knots, the left roll angle increased beyond the autopilot's 45° limit, and (at 1554:24.1) the autopilot disconnect warning began to sound. One second later, the stick shaker activated. The sudden disengagement of the autopilot (at 1554:24.125) greatly accelerated the left rolling moment that had been developing, suddenly putting the airplane in an unusual attitude. Although the pilots were likely surprised by the upset event, interpretation of the FDR data indicated that the pilots responded with control wheel inputs to counter the left roll within 1 second of the autopilot disengagement and continued to apply control inputs in an apparent attempt to regain control of the airplane until the FDR recording ceased.

Meteorological Factors

Although Comair flight 3272 was operating in winter weather conditions throughout its flight from the Cincinnati area to Detroit, CVR and weather information indicated that the airplane was operating above the cloud tops at its cruise altitude of 21,000 feet msl. Further, the temperatures at the altitudes flown during the en route phase of the flight were too cold to be conducive to airframe ice accretion, and examination of the FDR data did not reflect degraded airplane performance until later in the airplane's descent. Therefore, the Safety Board concludes that the airplane was aerodynamically clean, with no effective ice accreted, when it began its descent to the Detroit area.

A study conducted by the National Center for Atmospheric Research (NCAR) indicated that there was strong evidence for the existence of icing conditions in the clouds along the accident airplane's descent path below 11,000 feet msl. In addition, weather radar data showed generally light precipitation intensities in the area west of Detroit, with weather echoes of increasing intensity below 11,000 feet msl along the airplane's descent path. The weather radar

⁶ An engine torque split manifested itself during this application of power—at 1554:17, the FDR recorded torque values of 33.3 percent and 39.3 percent on the left and right engines, respectively. The engine torque split ranged from 6 to 10 percent between 1554:17 and 1554:22, when torque values (and the range of the torque split) began to increase abruptly. Simulator test flights that replicated the accident scenario demonstrated that the initial 6 to 10 percent torque split did not have a large aerodynamic effect on the airplane's left roll; however, the larger torque split that occurred later in the accident sequence had a significant aerodynamic effect.

data indicated that the highest precipitation intensities likely existed between 4,100 feet msl and 3,900 feet msl.

The NCAR research meteorologists reported that the average liquid water content (LWC) in the clouds near the accident site likely varied from 0.025 to 0.4 grams per cubic meter when averaged over the cloud depth. However, according to an NCAR research meteorologist, droplet size and LWC are rarely evenly distributed through the depth of a cloud; he stated that, in a typical cloud distribution, the larger droplet sizes with corresponding lower LWC would likely exist near the cloud bases, whereas smaller droplet sizes with higher LWC would typically exist near the cloud tops. He stated that the accident airplane might have encountered higher LWC values (0.5-0.8 grams per cubic meter) with smaller droplets (non-supercooled large droplets (SLD), 10-30 microns) near the cloud tops and lower LWC values (0.025 to 0.4 grams per cubic meter) with larger droplets (larger than 30 microns) near the cloud bases (consistent with the previously discussed weather radar data). Further, the NCAR research meteorologist stated, "if any SLD existed...it would have been more likely to be lower in the cloud...be mixed with smaller drops...the larger drops in the spectrum of those that may have existed there would have been in the 200-400 micron...range."

In addition, the accident airplane's descent path passed through an area of relatively low radar reflectivity during the 4 to 5 minutes before the accident. According to the NCAR report, the area of reduced reflectivity indicated that "the snow-making process was less efficient there, thus allowing a greater opportunity for liquid cloud to exist." Postaccident statements obtained from the other pilots who were operating along the accident airplane's flightpath (and passed through the area of low reflectivity) near the time of the accident indicated that they encountered widely variable conditions. For example, the pilots of Cactus 50 reported moderate rime icing with the possibility of freezing drizzle, the pilots of Northwest Airlines (NW) flight 272 encountered moderate-to-severe rime icing as soon as they leveled off at 4,000 feet msl, and the pilots of NW flight 483 reported no icing.

Comparison of data from the airplanes indicates that the differences in airframe ice accretion reported by the pilots can be attributed to slight differences in timing, altitude, location (ground track), airspeed, and icing exposure time (and time within the area of reduced reflectivity) of the airplanes. Based on weather radar information and pilot statements, the Safety Board concludes that the weather conditions near the accident site were highly variable and were conducive to the formation of rime or mixed ice at various altitudes and in various amounts, rates, and types of accumulation; if SLD icing conditions were present, the droplet sizes probably did not exceed 400 microns and most likely existed near 4,000 feet msl.

Aerodynamic Effect of the Ice Accretion

To help assess the type, amount, and effect of the ice that might have been accumulated by Comair flight 3272 during its descent, the Safety Board reviewed the available icing and wind tunnel research data, conducted additional airplane performance studies/simulations, and requested the National Aeronautics and Space Administration's (NASA's) assistance in conducting icing research tunnel (IRT) tests and computational studies. In addition, the Safety

Board reviewed wind tunnel test data obtained during research conducted by the FAA at the University of Illinois at Urbana/Champaign (UIUC).

The Safety Board's study of the accident airplane's aerodynamic performance indicated that it began to degrade from ice accumulation⁷ about 4½ to 5 minutes before the autopilot disengaged, as the airplane descended through 7,000 feet msl; the amount of degradation increased gradually as the airplane descended to 4,000 feet msl. Based on this gradual performance degradation, weather radar data that showed light precipitation intensities, pilot reports of moderate or less ice accretions,⁸ and the Safety Board and NCAR weather studies, it appeared likely that Comair flight 3272 encountered icing conditions that fell within the 14 CFR Part 25 appendix C envelope⁹ and/or the lower portion of the SLD icing range during its descent to 4,000 feet msl. Thus, the postaccident icing tunnel tests were performed using LWCs between 0.52 and 0.85 grams per cubic meter and water droplet sizes between 20 microns and 270 microns. Total air temperatures (TAT) used in the icing tunnel tests ranged between 26° F and 31° F (-3° C and -0.5° C),¹⁰ consistent with the static air temperature (SAT) values recorded by the FDR during the airplane's descent from 7,000 to 4,000 feet msl. The exposure time used in the icing tunnel tests was 5 minutes; additional runs were conducted under some test conditions to determine the effect that deicing boot activation had on cleaning the leading edge and on subsequent ice accretions.

The icing tunnel tests did not result in thick ice accumulation under any test condition (including SLD droplets); rather, the tests consistently resulted in a thin (0.25 inch accumulation or less), rough "sandpaper-type" ice coverage over a large portion of the airfoil's leading edge deicing boot surface area (and aft of the deicing boot on the lower wing surface in some test conditions). In addition, in many IRT test conditions, small (½ inch) ice ridges accreted along the leading edge deicing boot seams. According to NASA and Safety Board IRT test observers, the thin, rough ice coverages (and ice ridges, where applicable) that accreted on the EMB-120 wing were somewhat translucent and were often difficult to perceive from the observation window. The IRT observers further noted that IRT lighting conditions and cloud (spray) type greatly affected the conspicuity of the ice accumulation, making it difficult to perceive the ice accumulation during the icing exposure periods. Scientists at NASA's Lewis Research Center described the IRT ice accretions as mostly "glaze" ice, like mixed or clear ice in nature, although it looked slightly like rime ice when the IRT was brightly lighted for photographic documentation of the ice accretions because of its roughness. The Safety Board notes that it is possible that such an accumulation would be difficult for pilots to perceive visually during flight, particularly in low

⁷ Although the Safety Board considered other possible sources for the aerodynamic degradation (such as a mechanical malfunction), the physical evidence did not support a system or structural failure, and the FDR data indicated a gradual, steadily increasing performance degradation that was consistent with degradation observed by the Safety Board in data from events in which icing was a known factor.

⁸ All pilot reports indicated moderate or less ice accretions, except the pilots of NW flight 272, who reported that they encountered a trace of rime ice during the descent, then encountered moderate-to-severe icing at 4,000 feet msl about 2 minutes after the accident.

⁹ The Part 25 appendix C icing envelope specifies the water drop mean effective diameter, the LWC, and the temperatures at which the airplane must be able to safely operate; aircraft compliance must be demonstrated through analysis, experimentation, and flight testing.

¹⁰ These TATs are equivalent to SATs of 21° F (-6° C) to 25.5° F (-3° C).

light conditions. This type of accumulation would be consistent with the accident airplane's CVR, which did not record any crew discussion of perceived ice accumulation and/or the need to activate deicing boots during the last 5 minutes of the accident flight.

The location of rough ice coverage observed during the icing tunnel tests varied, depending on AOA; at lower AOAs, the ice accretions extended farther aft on the upper wing surface (to the aft edge of the deicing boot on the upper wing surface, about 7 percent of the wing chord at the aileron midspan), whereas at higher AOAs, the ice accretions extended farther aft on the lower wing surface. In some IRT test conditions, sparse feather-type ice accretion extended aft of the deicing boot coverage on the lower wing surface (which extends to about 10½ percent of the airfoil chord at the aileron midspan) as far as 30 to 35 percent of the airfoil's chord.¹¹

The density of the rough ice coverage also varied, depending on the exposure time; a sparse layer of rough ice usually accreted on the entire impingement area during the first 30 seconds to 1 minute of exposure, and the layer became thicker and more dense as exposure time increased. The NASA-Lewis and FAA/UIUC tests indicated that thin, rough ice accretions located on the leading edge and lower surface of the airfoil primarily resulted in increases in drag, while thin, rough ice accretions located on the leading edge and upper wing surface had an adverse effect on both lift and drag; this is consistent with information that has been obtained during National Advisory Committee for Aeronautics/NASA icing research conducted since the late 1930s. Data from research conducted in the 1940s and 1950s indicate that an airfoil's performance can be significantly affected by even a relatively small amount of ice accumulated on the leading edge area, if that accumulation has a rough, sandpaper-type surface.

Consistent with these data, NASA's drag calculations indicated that the thin, rough layer of sandpaper-type ice accumulation resulted in significant drag and lift degradation on the EMB-120 wing section. Further, the thin rough ice accumulation resulted in a decrease in stall AOA similar to that observed in wind tunnel tests with 3-inch ram's horn ice shapes on protected surfaces and frequently demonstrated a more drastic drop off/break at the stall AOA. FAA/UIUC conducted wind tunnel tests using generic shapes to represent the sandpaper-type roughness with ridges placed on the upper wing surface at 6 percent of the wing chord (farther aft than the ice ridges observed during NASA's IRT tests); these tests further demonstrated that the ridge type of ice accretion resulted in more adverse aerodynamic effect than the 3-inch ram's horn ice shapes.

¹¹ According to NASA-Lewis scientists, some of the frost accretion observed aft of the deicing boot on the lower wing surface during the icing tunnel tests might have been an artifact of the icing research tunnel (resulting from the higher turbulence, humidity, and heat transfer characteristics of the tunnel). However, the B.F. Goodrich impingement study (which predicts ice accretion impingement limits on an airfoil) and NASA's LEWICE computer program (which predicts the extent of ice accretion on the leading edges of airplane wings and impingement limits and ice thickness for specified conditions but cannot predict surface roughness features) also predicted a sparse, rough ice accretion aft of the deicing boot on the lower wing surface for some of the tested conditions. However, no ice accretion aft of the deicing boot was noticed during the natural icing certification tests. Although it is possible that some of the drag observed in the accident airplane's performance was the result of a sparse, rough ice accumulation aft of the deicing boot on the lower wing surface, it was not possible to positively determine whether the accident airplane's ice accretion extended beyond the deicing boot coverage.

As previously noted, NASA's IRT tests indicated that when an EMB-120 wing is exposed to conditions similar to those encountered by Comair flight 3272 before the accident, the airfoil tended to accrete a small ice ridge (or ridges) along the deicing boot tube segment stitchlines. During tests conducted at a TAT of 26° F, a small, but prominent ($\frac{1}{2}$ inch) ridge of ice frequently appeared on the forward portion (0.5 to 1 percent mean aerodynamic chord) of the leading edge deicing boot's upper surface.

The IRT test results were used in NASA's computational studies, which indicated that these pronounced ice ridges tended to act as stall strips, creating more disrupted airflow over the airfoil's upper surface, further decreasing the lift produced by the airfoil, and resulting in a lower stall AOA than the rough ice accretions alone. NASA's computational study data indicated that a thin, rough ice accretion with a small, prominent ice ridge can result in a lower stall AOA and a more dramatic drop off/break than the 3-inch ram's horn ice shape commonly used during initial icing certification testing.

The accident airplane's performance displayed evidence of adverse effects on both lift and drag during the airplane's descent to 4,000 feet msl. The degradation exhibited by the accident airplane was consistent with a combination of thin, rough ice accumulation on the impingement area (including both upper and lower wing leading edge surfaces), with possible ice ridge accumulation. Thus, based on its evaluation of the weather, radar, drag information, CVR, existing icing research data, and postaccident icing and wind tunnel test information, the Safety Board concludes that it is likely that Comair flight 3272 gradually accumulated a thin, rough glaze/mixed ice coverage on the leading edge deicing boot surfaces, possibly with ice ridge formation on the leading edge upper surface, as the airplane descended from 7,000 feet msl to 4,000 feet msl in icing conditions; further, this type of ice accretion might have been imperceptible to the pilots.

The Safety Board notes that in some icing exposure scenarios, pilots could become aware of the performance degradation without observing a significant accumulation of ice on the airplane by observing other cues, such as a decrease in airspeed, excessive pitch trim usage, a higher-than-normal amount of engine power needed to maintain a stabilized condition, and/or anomalous rates of climb or descent. However, the Safety Board concludes that because the pilots of Comair flight 3272 were operating the airplane with the autopilot engaged during a series of descents, right and left turns, power adjustments, and airspeed reductions, they might not have perceived the airplane's gradually deteriorating performance.

Further, although it is possible (based on the icing reported by the pilots of NW flight 272 and the NCAR scientist's estimation of the likely droplet size distribution in the clouds) that the accident flight encountered SLD icing¹² as it reached 4,000 feet msl, the airplane was only at that altitude for about 25 seconds before the upset occurred; during most of that 25 seconds, the FDR data showed that the autopilot was countering the increasing left roll tendency and a sideslip

¹² Results from the SLD icing tanker tests suggest that the visual cues for SLD ice accumulations (unusually extensive ice accreted on the airframe in areas not normally observed to collect ice, accumulation of ice on the upper surface of the wing aft of the protected area, and on the propeller spinner farther aft than normally observed) would have been very apparent to the pilots and might have resulted in a comment.

condition was developing. However, even if the accident flight had accumulated ice at the rapid rate reported by the pilots of NW flight 272 (about $\frac{1}{2}$ inch per minute), the accident flight could not have accumulated a large amount of ice during the brief period of time it spent at 4,000 feet before the autopilot disengaged and the loss of control occurred. Further, icing of the magnitude described by the pilots of NW flight 272 would have produced strong visual cues, and it is likely that the pilots would have commented on such a rapid accumulation, had it occurred. The accident airplane's CVR did not record any flightcrew comments about ice accumulation or the need to activate the leading edge deicing boots during the last 5 minutes of the accident flight; this is consistent with an ice accumulation that was either not observed by the pilots or that was observed but considered to be unremarkable.

Use of Deice/Anti-ice Equipment

The Safety Board attempted to determine whether the airplane's ice protection systems were operated during the accident airplane's descent and approach to DTW. CVR information showed that when the pilots performed the descent checklist at 1547, they confirmed that the airplane's "standard seven" anti-ice systems were activated and activated the windshield heat and the propeller deice system.¹³ This was consistent with guidance contained in Comair's EMB-120 Flight Standards Manual (FSM), which stated that anti-ice systems should be activated "before flying into known icing conditions" to prevent ice accumulation on the affected surfaces. Comair's EMB-120 FSM defined icing conditions as existing "when the OAT [outside air temperature] is $+5^{\circ}\text{C}$ or below and visible moisture in any form is present (such as clouds, rain, snow, sleet, ice crystals, or fog with visibility of one mile or less)."

For years, airplane manufacturers have incorporated leading edge deicing boots in the design of airplanes that are to be certificated for operation in icing conditions; the purpose of deicing boots is to shed the ice that accumulates on protected surfaces of the airframe. Over the years, leading edge deicing boots have demonstrated their effectiveness to operators and pilots by keeping the wing and tail leading edges relatively clear of aerodynamically degrading ice accumulations, to the point that operators and pilots have become confident that the airplanes can be flown safely in icing conditions as long as the airplane's deicing boots are operated (and functioning) properly. However, based on problems with earlier deicing boot designs (which used larger tubes and lower pressures, resulting in slower inflation/deflation rates), manufacturers, operators, and pilots developed the belief that premature activation of the leading edge deicing boots could (as cautioned in Comair's EMB-120 FSM) "result in the ice forming the shape of an inflated de-ice boot, making further attempts to deice in flight impossible [ice bridging]."¹⁴ Thus, at the time of the accident, Comair's (and most other EMB-120 operators') guidance indicated that pilots should delay activation of the leading edge deicing boots until they observed $\frac{1}{4}$ inch to $\frac{1}{2}$ inch ice accumulation, despite Embraer's FAA and Centro Tecnico Aeroespacial of Brazil (CTA) approved EMB-120 Airplane Flight Manual (AFM) revision 43, which indicated that pilots should activate the leading edge deicing boots at the first sign of ice accumulation.

¹³ Although Embraer's nomenclature identifies the propeller ice protection mechanism as a deicing system, it functions as an anti-icing system because it is activated before ice accumulates on the airframe.

The pilots' activation of the propeller and windshield ice protection systems when the airplane entered the clouds would indicate that they were aware that the airplane was operating in icing conditions. If they had activated the leading edge deicing boots, at least some of the airplane's degraded performance would have been restored. However, even if the pilots observed any of the thin, rough ice accretion that likely existed before the loss of control, they probably would not have activated the deicing boots because Comair's guidance to its pilots advised against activating the deicing boots until they observed a thicker ice accumulation. Therefore, based on CVR information and on the steady degradation of airplane performance that was clearly uninterrupted by leading edge deicing boot activation, the Safety Board concludes that, consistent with Comair's procedures regarding ice protection systems, the pilots did not activate the leading edge deicing boots during their descent and approach to the Detroit area, likely because they did not perceive that the airplane was accreting significant (if any) structural ice.

During the postaccident (November 1997) Airplane Deicing Boot Ice Bridging Workshop, information regarding recent icing tunnel and flight test research into the ice bridging phenomenon was disseminated and discussed among industry personnel. The recent research revealed that modern turbine-powered airplanes, with their high-pressure, segmented pneumatic deicing boots, are not at risk for ice bridging.¹⁴ However, in April 1996 when Embraer issued (FAA- and CTA-approved) revision 43 to the EMB-120 AFM, the procedure it recommended—activation of the leading edge deicing boots at the first sign of ice accretion—was not consistent with traditional industry concerns about ice bridging. According to the FAA's EMB-120 Aircraft Certification Program Manager, when the EMB-120 AFM revision was proposed by Embraer in late 1995, the deicing boot procedural change was very controversial and generated numerous discussions among FAA and industry personnel. The FAA's EMB-120 Aircraft Certification Program Manager stated that the aircraft evaluation group personnel involved in the discussions about the six EMB-120 icing-related events, the EMB-120 in-flight icing tanker tests, and the deicing boot procedural change were initially resistant to the deicing boot procedural change because of the perceived potential for ice bridging.

The Safety Board notes that during the winter of 1995/1996, senior Comair personnel (and representatives from other EMB-120 operators) were involved in numerous meetings and discussions regarding the six preaccident icing-related events and that they subsequently received Embraer's Operational Bulletin 120-002/96 and revision 43 to the EMB-120 AFM, with its controversial deicing boot procedural change. Although these discussions and documents apparently heightened senior Comair personnel's awareness and concern about EMB-120 operations in icing conditions (as evidenced by the December 1995 interoffice memo, entitled "Winter Operating Tips," and the October 1996 flight standards bulletin 96-04, entitled "Winter Flying Tips"), until the (postaccident) ice bridging workshop, there was insufficient information available to allay the company's concerns regarding the perceived hazards of ice bridging. Because Comair management personnel were still concerned that ice bridging was a problem for modern turbopropeller-driven airplanes, at the time of the accident, the company's deicing boot activation procedures had not been revised in accordance with AFM revision 43. The Safety Board recognizes the concerns regarding ice bridging that Comair had at the time of the accident

¹⁴ It is important to note that ice bridging may still be a potential hazard for airplanes with older technology deicing boots that have slower inflation/deflation rates.

(before the ice bridging workshop) and notes that the FAA had not mandated incorporation of the procedural revision or engaged in discussions with EMB-120 operators/pilots regarding the merit of the procedural change. Apparently, Comair was not the only EMB-120 operator with concerns regarding the deicing boot procedural change because the air carriers' records indicated that at the time of the accident, only two of seven U.S.-based EMB-120 operators had incorporated the revision into its procedural guidance. However, the Board is concerned that Comair's EMB-120 pilots did not have access to the most current information regarding operating the EMB-120 in icing conditions.

According to EMB-120 pilots from Comair and the Air Line Pilots Association (ALPA), their discussions with other EMB-120 flightcrews indicate that the procedural change is still a controversial issue, despite the information revealed during this accident investigation and at the November 1997 Airplane Deicing Boot Ice Bridging Workshop. This illustrates how thoroughly ingrained the ice bridging concept was in pilots and operators and the importance of an ice bridging pilot education program. Therefore, a thin, yet performance-decreasing type of ice (similar to that likely accumulated by Comair flight 3272) can present a more hazardous situation than a 3-inch ram's horn ice accumulation because it would not necessarily prompt the activation of the boots. Based on this information, the Safety Board concludes that the current operating procedures recommending that pilots wait until ice accumulates to an observable thickness before activating leading edge deicing boots results in unnecessary exposure to a significant risk for turbopropeller-driven airplane flight operations. Based primarily on concerns about ice bridging, pilots continue to use procedures and practices that increase the likelihood of (potentially hazardous) degraded airplane performance resulting from small amounts of rough ice accumulated on the leading edges.

The Safety Board is aware that the FAA, NASA, and ALPA plan to organize an industry-wide air carrier pilot training campaign to increase pilots' understanding of the ice bridging phenomenon and safe operation of deicing boots. Unfortunately, according to NASA personnel, the training program has not yet begun because the FAA is still developing its position based on information from the Ice Bridging Workshop. The Safety Board appreciates the FAA's intention to initiate the development of ice bridging training and its desire to ensure that the training is as thorough and accurate as possible; however, the Board is concerned that the planned training is being delayed. Further, the planned training primarily targets air carrier pilots, and the Board considers it important that the information be disseminated to all affected pilots/operators. The Safety Board is concerned that if nonair carrier pilots and operators do not receive the training, they may operate turbopropeller-driven airplanes in icing conditions using deicing boot procedures that result in less safe flight operations. A training program that reaches only a limited part of the pilot population may not be sufficient to eliminate the pervasive beliefs regarding the potential for ice bridging in turbopropeller-driven airplanes.

Therefore, the Safety Board believes that NASA should (with the FAA and other interested aviation organizations) organize and implement an industry-wide training effort to educate manufacturers, operators, and pilots of air carrier and general aviation turbopropeller-driven airplanes regarding the hazards of thin, possibly imperceptible, rough ice accumulations, the importance of activating the leading edge deicing boots as soon as the airplane enters icing conditions (for those airplanes in which ice bridging is not a concern), and the importance of

maintaining minimum airspeeds in icing conditions. The Safety Board encourages NASA and the FAA to expedite this training effort.

It is important to note that although leading edge deicing boots are useful in minimizing the adverse affects of ice accumulation on an airplane's protected surfaces, activation of deicing boots does not result in a completely clean boot surface; some residual ice remains on the deicing boot after it cycles, and intercycle ice accumulates between deicing boot cycles (on the EMB-120, during the 54-second or 174-second intervals, depending on the mode of boot operation selected). Icing tunnel tests indicate that when the deicing boots are activated early, the initial deicing boot cycle leaves a higher percentage of residual ice than it would with delayed deicing boot activation. However, when the deicing boots remained operating during the remainder of the ice encounter, subsequent deicing boot cycles resulted in a wing leading edge about as clean as would occur with delayed boot activation.

The FAA/UIUC wind tunnel tests revealed that even a thin, sparse (5 percent to 10 percent density ice coverage) amount of rough ice accumulation over the leading edge deicing boot coverage area resulted in significant aerodynamic degradation. This information raises questions about the effectiveness of leading edge deicing boots when dealing with this type of ice accumulation, especially considering a B.F. Goodrich estimation that a good, effective deicing boot shed leaves about 20 percent of the accumulated ice on the boots. The sparse ice coverage observed during the first 30 to 60 seconds of exposure time in some of NASA's icing tunnel test conditions (and which could occur between deicing boot cycles) was estimated by observers to be about 10 percent. This combined research indicates that it is possible for a hazardous situation to occur even if pilots operate the deicing boots early and throughout the icing encounter. The Westair flight 7233 incident, in which uncommanded roll and pitch excursions occurred despite the fact that the pilots stated that they had activated the leading edge deicing boots and selected the heavy boot operation mode,¹⁵ may be an example of such a hazardous situation.

In addition, a hazardous situation may develop even if deicing boots are operated throughout an icing encounter as a result of ice accretions on an airplane's unprotected surfaces, such as aft of the deicing boots. The B.F. Goodrich impingement study, NASA's LEWICE calculations, and NASA IRT tests indicated that a light accretion may occur on the unprotected lower wing surfaces aft of the deicing boot on the EMB-120. However, Embraer representatives stated that such an ice accretion would result in only a trace of ice accumulating aft of the deicing boots and would have a minimal aerodynamic penalty in drag only. Although there was no evidence of ice accretion aft of the deicing boot during the EMB-120 certification natural icing tests and it was not possible to determine whether the accident airplane's ice accretion extended aft of the deicing boot coverage, it is possible that ice accretion on the unprotected surface aft of the deicing boot could exacerbate a potentially hazardous icing situation.

¹⁵ According to the pilots of Westair flight 7233, they were aware that they were operating in "icing conditions;" they stated that they observed ice accumulating on the airplane and had activated the leading edge deicing boots when the airplane entered the clouds during their departure.

Based on icing and wind tunnel research and information from the Westair incident, the Safety Board concludes that it is possible that ice accretion on unprotected surfaces and intercycle ice accretions on protected surfaces can significantly and adversely affect the aerodynamic performance of an airplane even when leading edge deicing boots are activated and operating normally. Thus, pilots can minimize (but not always prevent) the adverse effects of ice accumulation on the airplane's leading edges by activating the leading edge deicing boots at the first sign of ice accretion. It is not clear what effect residual ice/ice accretions on unprotected nonleading edge airframe surfaces have on flight handling characteristics. Because not enough is known or understood about icing in general, and especially about the effects of intercycle and residual ice, the Safety Board believes that NASA should (with the FAA and other interested aviation organizations) conduct additional research to identify realistic ice accumulations, to include intercycle and residual ice accumulations and ice accumulations on unprotected surfaces aft of the deicing boots, and to determine the effects and criticality of such ice accumulations; further, the information developed through such research should be incorporated into aircraft certification requirements and pilot training programs at all levels.

Therefore, the National Transportation Safety Board makes the following recommendations to the National Aeronautics and Space Administration:

With the Federal Aviation Administration and other interested aviation organizations, organize and implement an industry-wide training effort to educate manufacturers, operators, and pilots of air carrier and general aviation turbopropeller-driven airplanes regarding the hazards of thin, possibly imperceptible, rough ice accumulations, the importance of activating the leading edge deicing boots as soon as the airplane enters icing conditions (for those airplanes in which ice bridging is not a concern), and the importance of maintaining minimum airspeeds in icing conditions. (A-98-107)

With the Federal Aviation Administration and other interested aviation organizations, conduct additional research to identify realistic ice accumulations, to include intercycle and residual ice accumulations and ice accumulations on unprotected surfaces aft of the deicing boots, and to determine the effects and criticality of such ice accumulations; further, the information developed through such research should be incorporated into aircraft certification requirements and pilot training programs at all levels. (A-98-108)

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in these recommendations.



By: Jim Hall
Chairman



National Transportation Safety Board

Washington D.C. 20594

Safety Recommendation

Date: September 14, 1998

In reply refer to: A-98-109 through -110

Honorable Jane F. Garvey
Administrator
Federal Aviation Administration
Washington, D.C. 20591

On October 15, 1997, about 1030 mountain daylight time, a Cessna P210N, N731NX, operated by the Sheriff's Department of Mesa County, Colorado, experienced an in-flight electrical fire while cruising at 16,500 feet over Bryce Canyon, Utah. The commercial pilot initiated an emergency descent and landed uneventfully in Bryce Canyon with minor damage. The pilot and his passenger were not injured. Visual meteorological conditions prevailed, and a visual flight rules flight plan had been filed. The public-use flight was conducted under Title 14 Code of Federal Regulations Part 91, and originated from Grand Junction, Colorado, about 60 minutes before the incident.

The Safety Board's investigation revealed that the fire originated on the cabin sidewall, under the left side of the instrument panel, and resulted in burned vinyl, plastic, and insulation material.¹ The fire was caused by an overheated resistor used in an electric door seal inflation system. The resistor was used to reduce the 28-volt aircraft electrical system's voltage to meet the power requirements of the door seal system's 14-volt air pump motor. The system had been installed on the airplane in accordance with a Federal Aviation Administration (FAA)-approved supplemental type certificate (STC)² that was issued to the system's manufacturer, Bob Fields Aerocessories, Inc., in 1983. The purpose of the system is to decrease in-flight cabin

¹ Bryce Canyon, Utah, October 15, 1997, Cessna P210N, N731NX (FTW98TA051).

² A supplemental type certificate can be issued by the FAA for design changes to type-certificated aircraft when the change is not so extensive as to require a new type certificate for that aircraft. STCs are typically approved for optional after-market kits that improve an aircraft design. The STC applicant must submit sufficient technical data to the FAA to show compliance with the applicable certification requirements.

noise caused by ill-fitting cabin doors. According to Bob Fields Aerocessories, about 20,000 of these systems are currently installed in a wide variety of single- and twin-engine general aviation airplanes.

Since the Bryce Canyon incident in October 1997, the Safety Board has investigated one accident and two incidents that also involved in-flight fires originating in electric inflatable door seal systems manufactured by Bob Fields Aerocessories. Moreover, a review of the FAA's Service Difficulty Report database revealed four additional reports of overheated components associated with the door seal system, three of which cited smoke in the cockpit. A description of the recent accident and incidents investigated by the Safety Board follows.

On November 20, 1997, a Beech 95-B55, N3681K, sustained substantial damage after impacting trees during a precautionary landing in Burlington, Kansas. The landing was precipitated by smoke and an electrical fire in the cabin during cruise flight at 6,500 feet. Postaccident examination of the airplane revealed that a Bob Fields Aerocessories electric door seal inflation pump, mounted on the forward side of the nose bulkhead, was heavily charred. The Safety Board determined that the probable cause of the accident was, in part, "the door seal inflation pump catching fire."³

On June 25, 1998, the pilot of a Cessna P210N, N5083W, initiated a precautionary landing in Ithaca, New York, after heavy smoke had entered the cabin during cruise flight at 5,000 feet. Immediately after the landing, airport fire and rescue personnel discovered a self-sustaining fire originating under the left side of the instrument panel. Vinyl, plastic, and insulation material had burned in the fire. Subsequent examination of the airplane revealed that one of the resistors used in the Bob Fields Aerocessories electric door seal inflation system installed on the airplane was partially melted.⁴ The Safety Board recently learned of a July 17, 1998, incident aboard a Beech 58 airplane in which the pilot reported a burning smell in the cockpit while in cruise flight. He landed in Toms River, New Jersey, and asked a mechanic to inspect the airplane. The mechanic reported that the pump assembly and resistors for the installed Bob Fields Aerocessories electric door seal inflation system, mounted in the nose compartment, were partially melted.⁵

The electric door seal inflation system manufactured by Bob Fields Aerocessories consists of an electric motor, an air pump, inflatable silicon door seals, a pressure sensing switch, an air supply control valve, a resistor assembly, a 7.5-amperes (amps) in-line fuse, a caution light, and electrical wiring. A 5-amp circuit breaker may also be provided as an option. The motor draws power directly from the airplane's battery bus and is used to inflate the door seals to a pressure of about 10 pounds per

³ For more detailed information, see Brief of Accident CHI98LA041 (enclosed).

⁴ Ithaca, New York, June 25, 1998, Cessna P210N, N5083W (NYC98SA138).

⁵ Toms River, New Jersey, July 17, 1998, Beech 58, N53RD (NYC98SA167).

square inch (psi). A sensor on the air pump determines when the pressure drops below 10 psi, at which time the air pump motor cycles back on until the proper pressure is achieved. According to the STC-holder, it takes between 4 and 12 seconds after system activation for the air pump to inflate the door seal; during this time, the caution light remains illuminated. If the door seal has a small leak, the pump cycles on and off to maintain the desired inflation pressure. If the door seal has a larger leak, the air pump may run continuously to keep the door seal inflated.

The Safety Board's review of the system design revealed that the system incorporates two identical 1-ohm resistors, each rated for a maximum of 50 watts. The resistors are wired close together and in series. According to technical specifications provided by the vendor of the resistor, the resistor's wattage capability should be derated to no more than 20 watts if it is not mounted onto a sufficiently sized conductive structure for heat dissipation. Test data from the vendor further indicate that the aluminum housing of a single resistor will heat up to 313° F when the resistor carries the nominal wattage of the door seal inflation system and is adequately mounted to provide for heat dissipation.⁶ The housing temperature rises to more than 600° F if the resistor is not mounted to conductive material for heat dissipation. The potential for overheating is increased by the two resistors being wired closely together.

The Safety Board reviewed the FAA-approved installation instructions for the Bob Fields Aeroaccessories electric inflatable door seal pump. The instructions state, "...be sure to mount the resistors pak [sic] to a metal plate to make a heat sink. This plate and resistors can be mounted at the parking brake support angle under the instrument panel." No other instructions are found related to the resistor mounting. The investigations into the Bryce Canyon, Ithaca, and Toms River incidents revealed that the resistors were either hanging freely, or were mounted to structure in a manner that was insufficient to dissipate the heat generated by the resistors. The Safety Board is concerned that the installation instructions are insufficient and do not provide enough detail or cautions regarding the proper installation of the resistors and the minimum specifications for a heat sink.

The Safety Board is also concerned about other aspects of the design of the door seal inflation system that can lead to the overheating of the resistors and other system components. The design calls for the system to be installed in confined areas on the aircraft. For example, in the two-door Cessna airplane models, the STC suggests that the system be mounted behind the pilot's "kick panel." The kick panel area is a confined space between the external skin of the airplane just forward of the door and an upholstered panel under the left side of the pilot's instrument panel. This space has limited ventilation and inhibits the cooling required for a continuously

⁶ The door seal inflation system draws a nominal current of 6 amps, thereby producing 36 watts of power through each 1-ohm resistor. Test data indicate that 36 watts of applied power through the specified resistor that is mounted on top of a box-shaped, aluminum chassis for heat conduction (0.040 inch thick, 5 inches wide, 7 inches long, and 2 inches deep) will produce a housing temperature of 313° F.

operating electrical pump and its associated resistors. The space also provides potentially combustible materials in close proximity to heated electrical components, as illustrated by the Bryce Canyon and Ithaca incidents.

Another aspect of the door seal inflation system design that could lead to overheating involves the endurance rating of the electrically driven air pump. According to the vendor that supplies the air pump to Bob Fields Aerocessories, the pump was originally designed to be plugged into an automotive cigarette lighter socket and was intended to be used for the emergency inflation of automobile tires. In a letter forwarded to the Safety Board, the vendor stated that the continuous use of the pump "should not exceed 10 minutes without stopping for 30 minutes" to prevent overheating. The application of the air pump for the pressurization of airplane door seals during flight is inappropriate because the pump may be required to operate for more than 10 minutes, or to run continuously if the door seal leaks. This was illustrated in the Bryce Canyon incident when the caution light was observed by the pilot to be continuously illuminated. The Safety Board is concerned that extended or continuous operation of the air pump will lead to excessive heat buildup, causing an excessive current draw, and will exacerbate the potential for overheating that already exists under the nominal current draw.

Examination of the in-line fuses for the Bryce Canyon, Ithaca, and Toms River incidents revealed that a fuse rated for 10 amps had been installed in the door seal inflation system, exceeding the 7.5-amp-rated fuse specified by the approved STC installation instructions. The Safety Board notes that excessive current draw may result in frequent blown fuses and may prompt the improper installation of a higher-rated fuse. Although the improper use of a 10-amp-rated fuse increases the potential for overheating components, the use of the specified 7.5-amp-rated fuse would not eliminate the hazard because, as discussed above, testing has shown that overheating of the resistors can occur at the nominal door seal inflation system current of 6 amps.

The Safety Board is also concerned that the electric door seal inflation system design does not provide adequate warning of a potential overheat situation. The system incorporates an amber (caution) light on the pilot's instrument panel that illuminates when the pump is operating. The STC installation instructions specify that a placard be placed near the light stating, "CAUTION/DOOR SEAL PUMP ON." However, no information is provided on action to take if the light remains illuminated for an extended period.

The Safety Board concludes that the Bob Fields Aerocessories door seal inflation system design does not provide owners or operators with adequate information about corrective action if the system begins to overheat. Also, it may not become apparent to an operator that the system is overheating until there are indications of an electrical fire. The system design does not incorporate its own electrical cut-off switch; therefore, the pilot's only means to address an overheating

system or component is to turn off the airplane's entire electrical power system using the master switch.

The Safety Board is very concerned that these design deficiencies increase the likelihood of an in-flight electrical fire and/or smoke in the cockpit during flight, as evidenced by the accident and incidents discussed above, as well as additional incidents identified by SDRs. Therefore, the Safety Board believes that the FAA should issue an airworthiness directive to require that all owners and operators of airplanes equipped with electric door seal inflation pump systems manufactured by Bob Fields Aerocessories immediately disconnect them from the airplanes' electrical systems. In addition, the FAA should review all STCs that provide for the installation of electric door seal inflation pump systems manufactured by Bob Fields Aerocessories, and require revisions, as necessary, to ensure that the hazards associated with in-flight fire and/or smoke in the cockpit during flight are eliminated. Existing systems should be required to comply with those instructions before they are placed back into service.

Therefore, the National Transportation Safety Board recommends that the Federal Aviation Administration:

Issue an airworthiness directive to require that all owners and operators of airplanes equipped with electric door seal inflation pump systems manufactured by Bob Fields Aerocessories immediately disconnect them from the airplanes' electrical systems. (Urgent) (A-98-109)

Review all supplemental type certificates that provide for the installation of electric door seal inflation pump systems manufactured by Bob Fields Aerocessories, and require revisions, as necessary, to ensure that the hazards associated with in-flight fire and/or smoke in the cockpit during flight are eliminated. Existing systems should be required to comply with those instructions before they are placed back into service. (A-98-110)

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in these recommendations.



By: Jim Hall
Chairman

Enclosure

National Transportation Safety Board
Washington, D.C. 20594

Brief of Accident

Adopted 01/30/98

CHI98LA041
FILE NO. 640 11/20/97 BURLINGTON, KS AIRCRAFT REG NO. N3681K TIME (LOCAL) - 08:30 CST

MAKE/MODEL -Beech-95-B55
ENGINE MAKE/MODEL -Continental IO-470-L
AIRCRAFT DAMAGE -Substantial
NUMBER OF ENGINES -2
OPERATING CERTIFICATES -NONE
TYPE OF FLIGHT OPERATION -Personal
REGULATION FLIGHT CONDUCTED UNDER -14 CFR 91

LAST DEPARTURE POINT - ROGERS, AR
DESTINATION - CONCORDIA, KS
AIRPORT PROXIMITY - Off airport/airstrip

PILOT-IN-COMMAND AGE - 39
CERTIFICATES/RATINGS
Private
Single-engine land, Multiengine land
INSTRUMENT RATINGS
Airplane

LAST DEPARTURE POINT - ROGERS, AR
DESTINATION - CONCORDIA, KS
AIRPORT PROXIMITY - Off airport/airstrip

WEATHER INFO SOURCE- Weather observation facility

BASIC WEATHER - Visual (VMC)
LOWEST CEILING - None
VISIBILITY - 8.000 SM
WIND DIR/SPEED - 180 /016 KTS
TEMPERATURE (F) - 42
OBSTR TO VISION - None
PRECIPITATION - None

PILOT-IN-COMMAND AGE - 39
CERTIFICATES/RATINGS
Private
Single-engine land, Multiengine land
INSTRUMENT RATINGS
Airplane

TOTAL ALL AIRCRAFT - 1323
LAST 90 DAYS - 38
TOTAL MAKE/MODEL - 201
TOTAL INSTRUMENT TIME - 221

FLIGHT TIME (Hours)

The pilot said they were about 40 minutes into their flight when "my passenger and I heard the pneumatic door seal give way." He recycled the switch, but nothing happened. A few minutes later, the pilot and passenger noticed "the faint smell of electrical burn." The pilot switched the heater off and the smell seemed to subside. He switched the heater back on and noticed a stronger smell immediately. Black smoke began to enter the cabin from above and beneath the instrument panel. The pilot said that as he reached for the throttle, he noticed "that there was orange spark and flame under the panel." He initiated a steep descent and began looking for a place to land. He located a north-south running dirt road, and initiated a 180-degree turn to land. The pilot overshot the road and landed in a field. During the landing, the airplane encountered uneven (rising) terrain and trees. An exam of the cabin revealed the door seal inflation pump was heavily charred. An exam of the cabin inflation seal around the cabin door was missing, both forward air vents were in the open position, and plastic insulation surrounding electrical wiring in front of the right air vent was melted. Melted plastic was observed on the floor, beneath the right side air vent. No other anomaly was found.

Brief of Accident (Continued)

CHI98LA041 FILE NO. 640	11/20/97	BURLINGTON, KS	AIRCRAFT REG NO. N3681K	TIME (LOCAL) - 08:30 CST
Occurrence# 1 Phase of operation	FIRE CRUISE			
Findings	1. AIR COND/HEATING/PRESSURIZATION - UNDETERMINED 2. EMERGENCY PROCEDURE - NOT PERFORMED - PILOT IN COMMAND 3. ELECTRICAL SYSTEM, ELECTRIC WIRING - MELTED			
Occurrence# 2 Phase of operation	IN FLIGHT COLLISION WITH OBJECT EMERGENCY LANDING			
Findings	4. PRECAUTIONARY LANDING - MISJUDGED - PILOT IN COMMAND 5. OBJECT - TREE (S)			
Occurrence# 3 Phase of operation	IN FLIGHT COLLISION WITH TERRAIN/WATER EMERGENCY LANDING			

The National Transportation Safety Board determines the probable cause(s) of this accident was: an undetermined event resulting in the door seal inflation pump catching fire, the Pilot's failure to close the cockpit air vents allowing heat and flames from the airplane's nose section to melt electrical wiring behind the instrument panel, and the pilot overshooting the road during his precautionary landing. A factor contributing to this accident was the trees.



National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: October 7, 1998

In reply refer to: A-98-111

Honorable Jane F. Garvey
Administrator
Federal Aviation Administration
Washington, D.C. 20591

On February 20, 1997, at 0645 central standard time, a Douglas DC-9-15, N93S, operated as Northwest Airlines (NWA) flight 219 under Title 14 Code of Federal Regulations Part 121, from Minneapolis, Minnesota, to Kansas City, Missouri, experienced an in-flight electrical fire, which filled the cockpit with smoke and fumes. The crew donned their oxygen masks and turned off both generators and the battery switch. They flew with a flashlight for 1 minute and then turned the emergency power switch on after the flames had extinguished themselves. The flightcrew declared an emergency, and the flight was diverted to the Des Moines International Airport, Des Moines, Iowa, and landed without further incident. None of the 4 crewmembers or the 32 passengers on board were injured, and the airplane sustained minor damage.

Examination of the airplane indicated that the electrical fire originated within the power distribution system's cross-tie relay, Westinghouse¹ part number (P/N) 914F567-4. The cross-tie relay allows either the left or right three-phase² alternating current (AC) generator to supply electrical power to all AC buses. Seven relays of this type are used in each DC-9 series airplane to provide electrical power source switching, including the cross-tie relay, left and right (L&R) generator relays (GR), L&R auxiliary power relays (APR), and L&R external power relays (EPR). These seven relays are mounted in the electrical power center (EPC) distribution panel in the cockpit.

Examination of the cross-tie relay from N93S revealed that the failure resulted from a phase-to-phase short,³ which was caused by the presence of main contact wear products

¹ Now Sundstrand Corporation.

² Comprises three single-phase windings that each produce a continuously alternating voltage/current.

³ Low resistance connection between two conductors normally insulated from each other (i.e. short circuit).

(debris) throughout the contact housing (arc box). NWA's records indicated that the relay had 35,160 hours total time and 7,775 hours since the last overhaul.

An examination of Douglas Aircraft Company⁴ (DAC) incident summary reports indicated that on November 5, 1974, a DC-9-31 experienced a similar cross-tie failure, during an approach for landing, in which smoke and sparks emitting from the EPC panel caused an emergency evacuation after landing. On June 5, 1975, another cross-tie relay caught fire in a DC-9-15 during taxi for takeoff. The smoke reportedly was so thick aft of the cockpit that the flight attendant was unable to locate the cockpit call button; she had to go to the rear of the aircraft to use the call button to inform the crew about the fire. Westinghouse concluded that the most likely cause of these failures was a phase-to-phase short within the relay.

As a result of this finding, on July 9, 1975, DAC notified all operators⁵ that all cross-tie relays with more than 7,000 hours service should be removed within 3,000 hours to be cleaned and inspected per Westinghouse Overhaul Manual 24-20-46, dated May 1, 1975. On July 1, 1975, Westinghouse issued Service Bulletin (SB) 75-701 to incorporate a more flame-resistant Lexan relay cover and improve the relay's internal wiring clearances. In March 1976, Westinghouse issued SB 75-703 to add a gasket seal to each of the interphase barriers of the contact housing and change the power relay assembly P/N from 914F567-3 to 914F567-4. The P/N 914F567-4 relay incorporates the changes recommended in SBs 75-701 and 75-703. Westinghouse informed operators that the reason for the change was to prevent phase-to-phase shorts resulting from the migration of main contact wear products through the contact housing interphase barriers. This modification was specifically recommended for all cross-tie relays. In June 1977, Westinghouse revised SB 75-703 to recommend, for the advantages of interchangeability, that this modification also be accomplished on all GRs, APRs, and EPRs.

On May 5, 1976, DAC issued All Operators Letter (AOL) 9-977 to recommend that all model DC-9, C-9A, and C-9B aircraft cross-tie relays be modified, in accordance with the two Westinghouse SBs, within 6,000 flight hours. The letter also informed operators that beginning with aircraft fuselage No. 850, subsequent production would have the improved power relay (P/N 914F567-4) installed in all seven relay positions.

On June 25, 1985, McDonnell Douglas⁶ (MD) issued AOL 9-1120A to advise operators that Westinghouse had developed an improved hybrid power relay, P/N 9008D09, which incorporated a deep cavity arc box and utilized magnetically held contacts, in lieu of the mechanically latched type formerly used by DAC. The design increased the recommended time between overhaul (TBO) to 12,000 flight hours, compared to the recommended TBO of 7,000 flight hours for the P/N 914F567-3 and -4 relays. On November 12, 1991, MD issued AOL 9-1120B to clarify the interchangeability between the old and new relay P/Ns. The operators were advised that the new relay, P/N 9008D09-X, was interchangeable with relay P/N 914F567-X, in all seven power relay positions on all DC-9 and MD-80 aircraft. The

⁴ Now Boeing, Douglas Products Division.

⁵ Telex DC-9-COM-31/HRG, dated July 9, 1975.

⁶ Now Boeing, Douglas Products Division.

letter also informed operators that the improved power relays would be installed at all seven relay positions during production for MD-80 aircraft, beginning with fuselage No. 909, and for all other DC-9 aircraft, beginning with fuselage No. 930.

A review of FAA service difficulty report (SDR) data for the period between January 1, 1974, and June 1, 1998, for Westinghouse relay P/Ns 914F567-3 and 914F567-4, indicated 21 reported failures. Numerous failures of the relay resulted in electrical power loss, smoke, and unscheduled landings. Many of the failures occurred in relays installed in positions other than the cross-tie location. The SDR data further revealed that several of the -3 and -4 relays had accumulated more than 7,000 flight hours at the time of failure, thereby exceeding the recommended TBO of 7,000 flight hours specified for these relays. One SDR, submitted in 1988, revealed that the operator had continued to utilize the P/N 914F567-3 relay in the cross-tie position subsequent to the 1976 issuance of DAC AOL 9-977.

Based on the February 20, 1997, NWA incident and the continued reports of AC power relay failures, the Safety Board is concerned about the ongoing potential for an electrical fire in the DC-9 series aircraft. This potential can be reduced by the modification of all existing P/N 914F567-3 relays to the -4 configuration and overhaul of the relays every 7,000 flight hours, before contaminants build to a level that will cause shorting between the main contacts of the power relay, or by their replacement with P/N 9008D09 relays. Therefore, the Safety Board believes that the FAA should issue an airworthiness directive to require that DC-9 operators modify all existing Westinghouse P/N 914F567-3 AC power relays (i.e. cross-tie relays, GRs, APRs, and EPRs) to the -4 configuration, in accordance with DAC AOL 9-977, dated May 5, 1976, and overhaul the relays every 7,000 flight hours thereafter or replace these relays with the improved power relay, P/N 9008D09.

Therefore, the National Transportation Safety Board recommends that the Federal Aviation Administration:

Issue an airworthiness directive to require that DC-9 operators modify all existing Westinghouse part number (P/N) 914F567-3 alternating current power relays (i.e. cross-tie relays, generator relays, auxiliary power relays, and external power relays) to the -4 configuration, in accordance with Douglas Aircraft Company All Operators Letter 9-977, dated May 5, 1976, and overhaul the relays every 7,000 flight hours thereafter or replace these relays with the improved power relay, P/N 9008D09. (A-98-111)

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in this recommendation.

By:

Jim Hall
Chairman



National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: November 4, 1998
In reply refer to: A-98-112

Honorable Jane F. Garvey
Administrator
Federal Aviation Administration
Washington, D.C. 20591

On March 15, 1997, a Piper PA-31 airplane, operated by Cape Smythe Air Service as a scheduled commuter flight from Kivalina, Alaska, to Kotzebue, Alaska, landed with the left main landing gear (MLG) partially retracted at the Kotzebue Airport. None of the occupants was injured, and the airplane sustained minor damage.

Before landing, the pilot attempted to lower the landing gear; however, the landing gear did not extend normally, and the landing gear unsafe light illuminated in the cockpit. During a subsequent low pass over the airfield, ground personnel confirmed that the left MLG was not extended. Postincident examination revealed that a forward hinge on the left MLG inboard door had broken and disabled the door, preventing the gear from extending fully.

The PA-31 MLG inboard door is configured with two hinge assemblies that attach the door to the airplane, allowing the door to open during gear extension. There are two MLG inboard door hinge assemblies made for the PA-31: the original equipment hinge assembly (Piper part number (P/N) 46653-00) and an improved (thicker) hinge assembly (Piper P/N 47529-32). The improved hinge assembly consists of a 0.44-inch-thick, aluminum-forged hinge with two attachment angles.

The airplane had been operated for 13,988 hours in 17 years and 6 months of service and had been retrofitted with the improved hinge assemblies in 1988. The airplane had operated approximately 9,938 hours with the improved hinge assemblies before the hinge failure.

The National Transportation Safety Board's materials laboratory examined the fracture surfaces of the broken hinge. The examination revealed a fatigue crack that had emanated from multiple origins at the tip of the forged flash¹ on the inside curve portion of the hinge

¹ Excess metal that is forced out during the forging operation, between the upper and lower forging dies.

arm (see figure 1). The arm is subjected to cyclic loading during service, and the forging flash is a high-stress region of the hinge.

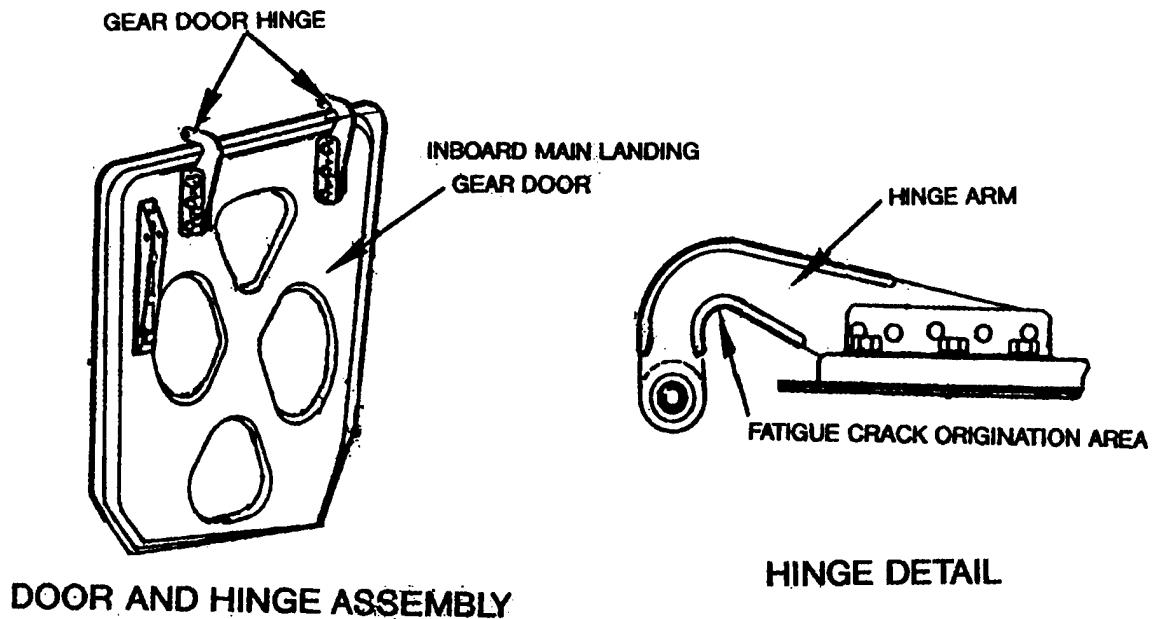


Figure 1. Piper PA-31 Main Landing Gear Door Assembly

In 1980, following several incidents of fatigue cracks in the original hinge, Piper Aircraft Corporation (now New Piper Aircraft, Inc.) issued Service Bulletin (SB) 682, which recommends inspection of the PA-31 MLG inboard door hinge assemblies and hinge attachment angles for cracks within the first 100 hours of operation or during the next scheduled inspection, whichever occurs first, and every 100 hours thereafter unless/until an acceptable replacement part is installed. The SB recommends that all cracked door hinges be replaced with the improved P/N 47529-32 hinge assemblies before further flight. Upon installation of the improved hinge assembly, repetitive inspection of the hinge assembly is not required. On December 19, 1980, the Federal Aviation Administration (FAA) issued Airworthiness Directive 80-26-05, mandating the actions specified in this SB.

However, despite these inspection and replacement procedures, service difficulty reports (SDR) indicate that since 1980 there have been at least 17 cracked or failed P/N 47529-32 hinge assemblies. Because experience has shown that the SDR system frequently underreports service failures, it is very likely that there have been other unreported events involving P/N 47529-32 hinge assembly failures. For example, the Safety Board's materials laboratory has examined another P/N 47529-32 hinge that separated because of fatigue cracking but there was no SDR report of the incident.

The Safety Board is concerned that the improved P/N 47529-32, PA-31 MLG inboard door hinge assemblies are failing and that no requirement exists for their recurrent inspection. Piper has indicated its intent to design a new sheet-metal hinge assembly that will replace the

P/N 47529-32 hinge assembly to preclude further failures. Therefore, the Safety Board believes that the FAA should require PA-31 operators to conduct repetitive inspections for cracks of all Piper P/N 47529-32 MLG inboard door hinge assemblies until they are replaced by an improved MLG inboard door hinge assembly that is not prone to similar failures.

Therefore, the National Transportation Safety Board recommends that the Federal Aviation Administration:

Require Piper PA-31 operators to conduct repetitive inspections for cracks of all Piper part number 47529-32 main landing gear (MLG) inboard door hinge assemblies until they are replaced by an improved MLG inboard door hinge assembly that is not prone to similar failures. (A-98-112)

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in this recommendation.

By: Jim Hall
Chairman



National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: October 26, 1998

In reply refer to: A-98-113 through -118

Honorable Jane F. Garvey
Administrator
Federal Aviation Administration
Washington, D.C. 20591

On June 18, 1998, a Swearingen SA226-TC Metroliner II airplane,¹ Canadian registry C-GQAL, operated by PropAir, Inc., crashed after the left wing separated during an attempted emergency landing at Mirabel Airport, Montreal, Quebec, Canada. The flight was operating as a charter from Montreal to Peterborough, Ontario, Canada. The airplane had departed from Montreal's Dorval Airport and was climbing through 12,500 feet when the flightcrew reported a loss of hydraulic pressure and a fire on the left side of the airplane. The pilot then shut down the left engine and declared an emergency. The flightcrew lost control of the airplane at low altitude during the final approach for landing. The airplane was destroyed, and the two flightcrew members and all nine passengers were killed.

The National Transportation Safety Board is participating in the Transportation Safety Board (TSB) of Canada's ongoing investigation under the provisions of Annex 13 to the Convention on International Civil Aviation. On the basis of the preliminary findings of the investigation, the Safety Board has concluded that the Federal Aviation Administration (FAA) should address several safety issues.

The airplane involved in the Montreal accident was equipped with B.F. Goodrich part number (P/N) 2-1203 wheel brake assemblies (see figure 1).² The left wheel well included the

¹ Swearingen Aviation Corporation was the original manufacturer of SA226 and SA227 series airplanes. Fairchild Aircraft, Inc., subsequently acquired Swearingen and continued the production of these airplanes.

² The B.F. Goodrich P/N 2-1203 series brake assembly is a floating-type, single-disk assembly. The steel disk has smooth sides, expansion slots, and tangs around the outer diameter. The tangs are keyed into the wheel so that both rotate together. The disk floats in and out of the wheel to prevent binding during brake application. The cast-aluminum alloy housing, which is bolted to the landing gear strut, has six cylinders, aluminum alloy pistons, and O-rings to prevent leakage. Each piston is protected from the brake pad by an asbestos piston insulator to minimize heat transfer from the disk to the piston. During brake application, hydraulic fluid is forced into the cylinder, and the piston pushes against the insulator, movable brake pad, disk, and opposing brake pad and torque plate to clamp the rotating disk. The airplane involved in the Montreal accident had the original design P/N 2-1203 wheel brake assembly. Subsequent P/N 2-1203 brake assemblies have suffixes of -1 through -4.

hydraulic power pack, a main landing gear (MLG) assembly, aluminum fuel and hydraulic lines and fittings, an overheat sensor, and a rubber fuel crossover line. The overheat sensor illuminates the L WING OVHT (left wing overheat) warning light on the pilot's annunciator panel when temperatures in the wheel well reach 350°F.³ Although the heavier Fairchild/Swearingen model SA227 airplanes (and other commuter and corporate airplanes of the approximate weight) incorporate in the MLG wheels fuse plugs that melt when hot, causing a gradual release of nitrogen pressure and preventing a tire burst, the SA226 does not incorporate such fuse plugs.

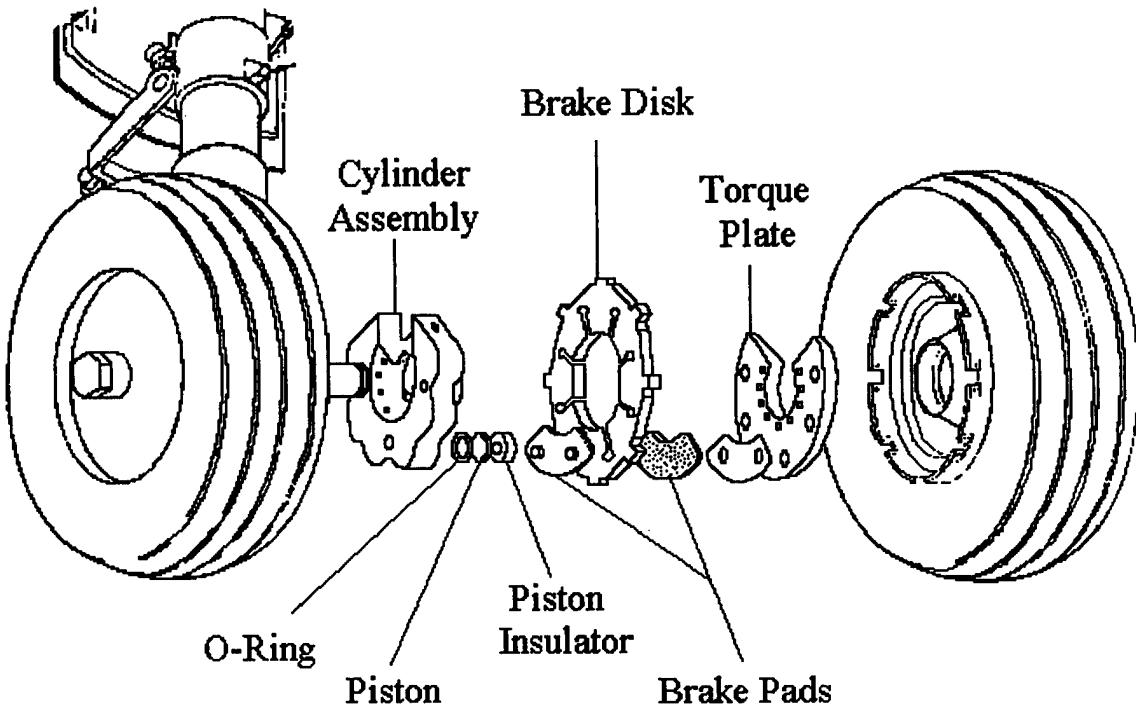


Figure 1. B.F. Goodrich 2-1203 Disk Brake Assembly

The preliminary results of the investigation revealed that, during the takeoff roll, the flightcrew applied the right rudder because the airplane was apparently veering toward the left side of the runway. Approximately 13 minutes after takeoff, the flightcrew noted a loss of hydraulic pressure and the illumination of multiple warning lights, including the left wing overheat warning light. Meanwhile, a passenger reported that the left engine was on fire. The captain later reported that the fire was extinguished and that the back of the engine appeared to have exploded. However, while executing the instrument approach, approximately 1 minute before impact, the flightcrew reported that the fire had resumed. The flightcrew manually extended the landing gear after descending through 1,000 feet, shortly before the left wing failed.

Examination of the wreckage at TSB's facility in Ottawa revealed extensive fire damage to the left MLG wheel well, overheated left MLG brake assemblies, burned tires, melted aluminum

³ A similar sensor is installed in the right wheel well.

hydraulic and fuel lines and fittings, and a burned rubber fuel crossover line. Witness marks on the inside of the brake cylinders and on the outside of the piston insulators indicated that the pistons were cocked within their respective cylinders. Most of the brake pads were worn unevenly, exposing the base metal. The piston insulators and brake disks were also worn unevenly; however, the wear on the disks was within the minimum thickness requirements specified in the airplane's maintenance manual. Although the airplane's main and brake hydraulic systems had a placard specifying MIL-H-83282, analysis of the fluid in both systems revealed a mixture of MIL-H-83282 and MIL-H-5606 hydraulic fluids.⁴ The mixed fluids had a flash point of approximately 237°F.

The investigation thus far indicates that the flightcrew applied the right rudder during the takeoff roll probably to compensate for a dragging left wheel brake and then raised the landing gear, with overheated brakes, into the left wheel well. Although the precise cause of the wheel well fire has not yet been determined, the investigative findings indicate that the ensuing fire in the left wheel well may have been caused by either (1) leaking low flash point brake system hydraulic fluid from a brake cylinder or (2) leaking fluid from damaged lines in the wheel well from an exploding tire coming in contact with and being ignited by the hot brake disk. The fire became hotter as additional flammable liquids from the brake, hydraulic, and fuel systems were introduced. This fire likely led to the wing failure. Leaking brake cylinders could have been caused by the cocked pistons, which appear to have resulted from the combined effects of excessive and uneven brake pad wear, uneven disk wear, and unevenly worn piston insulators on the outboard brake.

Use of Lower Flash Point Hydraulic Fluid

The accident and incident history of Fairchild/Swearingen SA226 and SA227 series airplanes revealed two previous cockpit fire accidents that involved the lower flash point MIL-H-5606 hydraulic fluid. On October 15, 1982, a Sun Aire Swearingen SA226-TC Metroliner II caught fire in Palm Springs, California, when an electrical arc from the copilot's panel light rheostat ignited wires, contaminated with hydraulic fluid from the right brake line, underneath the side panel. Additionally, on August 27, 1983, a Scheduled Skyways Swearingen SA226-TC Metroliner II caught fire in Hot Springs, Arkansas, when an electrical arc ignited wires, contaminated with hydraulic fluid, underneath the instrument panel.⁵

After the investigations of these two accidents, the Safety Board issued Safety Recommendation A-83-59, which asked the FAA to require operators to comply with Fairchild Service Bulletin (SB) 32-018 and use fire-retardant hydraulic fluid. As a result, the FAA issued Airworthiness Directive (AD) 83-19-02 on September 29, 1983,⁶ which required operators of

⁴ According to Air Force Aero Propulsion Laboratory Report AFAPL-TR-85-2057, MIL-H-5606 is a mineral oil product with a flash point of approximately 194°F, and MIL-H-83282 is a synthetic hydrocarbon with a flash point of approximately 390°F. Although the fluids are chemically compatible, mixing MIL-H-83282 with as little as 5 percent of MIL-H-5606 can render the first fluid's fire-retardant feature ineffective.

⁵ For more detailed information on these two accidents, see Briefs of Accident DCA83AA037 and LAX83FA002 (enclosed).

⁶ A similar directive was issued by the Canadian government's aviation regulatory authority, Transport Canada.

certain Swearingen SA226 series airplanes, including the airplane involved in the accident in Montreal, to drain and purge the main hydraulic and brake system reservoirs and refill them with MIL-H-83282 hydraulic fluid.⁷ The AD also required that operators change the placards on both reservoirs to specify that only MIL-H-83282 fluid be used. On February 21, 1984, the Safety Board classified this recommendation "Closed—Acceptable Action."

Although AD 83-19-02 and Fairchild's airplane maintenance manual required the use of MIL-H-83282 hydraulic fluid in the main and brake hydraulic systems in Swearingen SA226 and SA227 series airplanes, respectively, the Safety Board is concerned that the use of the lower flash point MIL-H-5606 or the mixing of MIL-H-5606 with MIL-H-83282 may be occurring. Therefore, the Safety Board believes that the FAA should require principal maintenance inspectors to notify operators of Fairchild/Swearingen SA226 and SA227 series airplanes of the Montreal accident and the requirement to use only the higher flash point MIL-H-83282 hydraulic fluid in all B.F. Goodrich P/N 2-1203 series brake systems.

Brake Assembly Overheating

The accident and incident history of Fairchild/Swearingen SA226 and SA227 series airplanes also revealed two previous wheel well fire accidents. On July 27, 1988, a Peninsula Airways Fairchild SA227-AC Metroliner III experienced a loss of hydraulic pressure, wheel well and wing overheat indications, exploded tires, and substantial fire damage in the left wheel well.⁸ The flightcrew made a successful emergency landing at Anchorage International Airport in Alaska. Additionally, on February 10, 1990, a Perimeter Airlines Swearingen SA226-TC Metroliner II similarly experienced a loss of hydraulic pressure, wheel well and wing overheat indications, exploded tires, and substantial fire damage to the left wheel well. The flightcrew shut down the left engine and made a successful emergency landing at Winnipeg International Airport in Canada.⁹

As a result of its investigation into the Anchorage incident, the Safety Board issued Safety Recommendation A-89-101, asking the FAA to conduct a directed safety investigation of the Fairchild SA226 and SA227 wheel braking systems that utilize the B.F. Goodrich P/N 2-1203-3 wheel brake assembly to (1) determine the potential for brake lockups or overheating as a result of piston insulator cocking and (2) evaluate the current wear limits for proper brake operation at the maximum wear allowed. The FAA reviewed the 5-year history of service difficulty reports regarding B.F. Goodrich brake malfunctions and discovered that 75 reports, including 9 incidents of MLG brake or wheel well fires, had been filed. On October 26, 1989, B.F. Goodrich issued Service Letter (SL) 1498 to clarify the proper location to take wear measurements for all P/N 2-1203 series brake assemblies and revise the maximum allowable clearance for brake assembly P/N 2-1203-3 to reduce the brake lining wear allowed before required overhaul. The FAA issued a special notice to FAA inspectors to alert them that SL 1498 revised the method of determining brake wear and the brake wear limit for P/N 2-1203 brake assemblies, and Fairchild

⁷ The Fairchild/Swearingen SA227 series airplane maintenance manual already specified the use of MIL-H-83282 in the main and brake hydraulic systems.

⁸ For more detailed information, see Brief of Accident ANC88FA100 (enclosed).

⁹ For more detailed information, see Aviation Occurrence Report synopsis A90C0024 (enclosed).

revised its maintenance manual accordingly. On June 18, 1990, the Safety Board classified this recommendation "Closed—Acceptable Action."

Also, the Safety Board issued Safety Recommendation A-89-102, asking the FAA to take appropriate action to prevent brake binding and overheating of B.F. Goodrich P/N 2-1203-3 brake assemblies. On January 16, 1992, the FAA issued AD 92-01-02, which required that operators of SA226 and SA227 airplanes equipped with B.F. Goodrich P/N 2-1203-3 brakes inspect and conduct wear measurements in accordance with SL 1498 and that operators of certain SA226 and SA227 airplanes modify the parking brake system in accordance with Fairchild SBs 227-32-017 and 226-32-049.¹⁰ On March 24, 1992, the Safety Board classified this recommendation "Closed—Acceptable Action."

The wear measurement techniques specified in the component maintenance manual, SL 1498, and AD 92-01-02 were intended to measure the amount of brake wear. However, the techniques were not designed to measure or detect the degree of uneven wear, which could lead to cocked pistons and result in dragging brakes, hydraulic fluid leakage, and wheel well fires. Therefore, the Safety Board believes that the FAA should require B.F. Goodrich to develop and implement a process for identifying and eliminating excessive uneven wear on all B.F. Goodrich P/N 2-1203 series wheel brake assemblies used on Fairchild/Swearingen SA226 and SA227 series airplanes.

Need for Improved Emergency Procedures to Address Wheel Well Fires

The SA226-TC airplane flight manual (AFM) states that, after the illumination of a wing overheat warning light, the flightcrew should secure the bleed air from the affected engine and extend the landing gear. The flightcrew involved in the Montreal accident apparently noticed a loss of hydraulic pressure and the left wheel well and wing overheat warning light but did not extend the landing gear until just before impact. In this accident, immediate extension of the landing gear might have prevented failure of the left wing.

The AFM emergency procedure to address the illumination of the wheel well and wing overheat warning light assumes that the cause is an air conditioning duct overheat and does not consider the consequences of a wheel well fire and the loss of hydraulic pressure or other airplane systems. For example, the procedure calls for shutting down the engine on the affected side of the airplane, which would be appropriate for an air conditioning duct overheat or a bleed air leak but unnecessary for a brake fire. Therefore, the Safety Board believes that the FAA should require Fairchild to (1) expand the description of the wing and wheel well overheat annunciator panel warning light in all Fairchild/Swearingen SA226 and SA227 series AFMs to note that a L or R WING OVHT annunciation may indicate a brake or wheel well fire and (2) expand the emergency procedure for a wheel well and wing overheat warning annunciation to address a wheel well fire and the consequences of other airplane system failures as a result of the fire.

¹⁰ The requirement for the parking brake system is not relevant to the issues discussed in this safety recommendation letter.

The Safety Board is also concerned about the vulnerability of the MLG wheel well in all Fairchild/Swearingen SA226 and SA227 series airplanes to the consequences of overheated brakes and wheel well fires. In the Montreal accident, the heat from the wheel well fire consumed the rubber fuel crossover line, melted aluminum fuel and hydraulic system lines and fittings, and allowed flammable fluid to be introduced to the wheel well fire. In addition, the wheel well might have incurred damage from bursting tires. A brake temperature monitoring or overheat detection system could have provided the pilots with an earlier warning of an overheating brake. Also, the introduction of flammable fluids may have been prevented had the airplane been equipped with stainless steel, rather than aluminum, hydraulic and fuel lines; a heat-resistant fuel crossover line; or fuse plugs such as those already installed in the higher gross weight SA227 series airplanes. Therefore, the Safety Board believes that FAA should require the modification of Fairchild/Swearingen SA226 and SA227 series airplanes to (1) include the installation of a brake temperature monitoring or overheat detection system; (2) provide protection to keep tires from exploding; and (3) protect the lines, fittings, and tubing installed in the wheel wells from hazards associated with exploded tires and fire.

Therefore, the National Transportation Safety Board recommends that the Federal Aviation Administration:

Require principal maintenance inspectors to notify operators of Fairchild/Swearingen SA226 and SA227 series airplanes of the Montreal accident and the requirement to use only the higher flash point MIL-H-83282 hydraulic fluid in all B.F. Goodrich part number 2-1203 series brake systems. (A-98-113)

Require B.F. Goodrich to develop and implement a process for identifying and eliminating excessive uneven wear on all B.F. Goodrich part number 2-1203 series wheel brake assemblies used on Fairchild/Swearingen SA226 and SA227 series airplanes. (A-98-114)

Require Fairchild to (1) expand the description of the wing and wheel well overheat annunciator panel warning light in all Fairchild/Swearingen SA226 and SA227 series airplane flight manuals to note that a L or R WING OVHT annunciation may indicate a brake or wheel well fire and (2) expand the emergency procedure for a wheel well and wing overheat warning annunciation to address a wheel well fire and the consequences of other airplane system failures as a result of the fire. (A-98-115)

Require the modification of Fairchild/Swearingen SA226 and SA227 series airplanes to

- (1) include the installation of a brake temperature monitoring or overheat detection system; (A-98-116)
- (2) provide protection to keep tires from exploding; (A-98-117) and

(3) protect the lines, fittings, and tubing installed in the wheel wells from hazards associated with exploded tires and fire. (A-98-118)

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in these recommendations.

A handwritten signature in black ink, appearing to read "jim hall". The signature is enclosed within a roughly oval-shaped outline.

By: Jim Hall
Chairman

Enclosures

National Transportation Safety Board
Washington, D.C. 20594

Brief of Accident

LAX83FA002 File No. - 2077 10/15/82 PALM SPRINGS,CA

Basic Information-----

Type Operating Certificate-AIR CARRIER

Commuter air carrier
-Scheduled,Domestic,Passenger
Flight Conducted Under
-14 CFR 135
Accident Occurred During
-STANDING

Aircraft Information-----

Make/Model - SWEARINGEN SA-226TC
Landing Gear - Tricycle-retractable
Max Gross Wt - 12500
No. of Seats - 20

A/C Reg. No. N63SA

Aircraft Damage

Substantial	Fatal	Serious	Injuries
Fire	Crew	0	Minor
ON GROUND	Pass	0	0

Time (Loc) - 1957 PDT

Environment/Operations Information-----

Weather Data
Wx Briefing
Method
Completeness
Basic Weather
Wind Dir/Speed
Visibility
Cloud Conditions(1st)
Cloud Conditions(2nd)
Obstructions to Vision
Precipitation
Condition of Light

- Company	Itinerary	Last Departure Point	Airport Proximity
- In person		PALM SPRINGS,CA	On airport
- Full	Destination	LOS ANGELES,CA	
- VMC			Airport Data
- 290/008 KTS			PALM SPRINGS
- 50.0 SM			Runway Ident
- NONE	ATC/Airspace		- N/A
- NONE	Type of Flight Plan		Runway Lft/Wid
- None	Type of Clearance		- N/A
- None	Type Apch/Indg		Runway Surface
- None			- N/A
- Night			Runway Status

Personnel Information-----

Pilot-In-Command
Certificate(s)/Rating(s)
ATP
SE land,ME land

Age - 27 Medical Certificate - Valid medical-no waivers/limit
Biennial Flight Review Flight Time (Hours)
Current - YES Total - 5100 Last 24 Hrs - 0
Months Since - 1 Make/Model- 3600 Last 30 Days - 80
Aircraft Type - SA-226 Instrument - 430 Last 90 Days- 250
Multi-Eng - 4200 Rotorcraft - 0

Instrument Rating(s) - Airplane

Narrative--

WHILE AT THE GATE WITH THE PASSENGERS SEATED & THE ENGINES RUNNING, THE COPILOT ATTEMPTED TO TURN UP HIS PANEL LIGHTS WITH THE RHEOSTAT LOCATED ON THE FAR RIGHT FORWARD PORTION OF THE SIDE ELECTRICAL PANEL. AT THAT INSTANT SMOKE BEGAN TO ERUPT AT HIS RIGHT KNEE POSITION. THE PASSENGERS WERE EVACUATED & THE COCKPIT FIRE WAS PUT OUT BY THE GROUND CREW. THE RHEOSTAT WAS FOUND TO BE CONTAMINATED WITH HYDRAULIC FLUID, & HEAVY ARCING WAS FOUND ON THE RHEOSTAT AT THE FULL HIGH POSITION. THREE HYDRAULIC LINES WERE FOUND TO BE BURNED IN HALF FORWARD & UNDER THE CIRCUIT BREAKER PANEL ACCESS DOOR. EXAMINATION OF THE HYDRAULIC BRAKE LINE REVEALED STRESS CRACKS DUE TO CHEMICAL CONTAMINATION OR FATIGUE, PERMITTING BRAKE FLUID TO ESCAPE INTO THE SURROUNDING AREA. THE BRAKE FLUID WAS IGNITED BY THE ARCING COPILOT'S RHEOSTAT. & THE FIRE REACHED AN OXYGEN LINE WITHIN SECONDS CAUSING A BLOW-OUT HOLE THRU THE FUSELAGE.

Occurrence #1 FIRE/EXPLOSION
Phase of Operation STANDING - ENGINE(S) OPERATING

Findings

1. LIGHT CONDITION - DARK NIGHT
2. INSTRUMENT LIGHTS - CONTAMINATION
3. INSTRUMENT LIGHTS - ARCING
4. HYDRAULIC SYSTEM,LINE - CONTAMINATION
5. HYDRAULIC SYSTEM,LINE - DUMPED
6. HYDRAULIC SYSTEM,LINE - FAILURE, PARTIAL
7. HYDRAULIC SYSTEM,LINE - LEAK
8. HYDRAULIC SYSTEM,LINE - BURNED
9. FUSELAGE, INSTRUMENT/ELECTRICAL PANEL - BURNED
10. OXYGEN SYSTEM, CREW - EXPLODED

Prabhakle *Canse...*

The National Transportation Safety Board determines that the Probable Cause(s) of this accident is/are finding(s) 2,3,4,5,6,7,8,9,10

National Transportation Safety Board
Washington, D.C. 20594

Brief of Accident

MAKE/MODEL	AIRCRAFT REG. NO. N503SS	TIME (LOCAL) - 20:03 CDT
ENGINE MAKE/MODEL	- SWEARINGEN SA226TC	
AIRCRAFT DAMAGE	- AIRESEARCH TPE-331	
NUMBER OF ENGINES	- Substantial	
OPERATING CERTIFICATES	- 2	
NAME OF CARRIER	- Commuter air carrier	
TYPE OF FLIGHT OPERATION	- SCHEDULED SKYWAYS INC. - Scheduled - Domestic - Passenger	
REGULATION FLIGHT CONDUCTED UNDER - 14 CFR 135		
LAST DEPARTURE POINT	- DALLAS, TX	CONDITION OF LIGHT - Dusk
DESTINATION	- LITTLE ROCK, AR	
AIRPORT PROXIMITY		WEATHER INFO SOURCE - Unk/Nr
AIRPORT NAME	- On airport	
RUNWAY IDENTIFICATION	- MEMORIAL FIELD	
RUNWAY LENGTH/WIDTH (Feet)	- 05	
RUNWAY SURFACE	- 6595/ 150	
RUNWAY SURFACE CONDITION	- Asphalt	
	- Dry	
PILOT-IN-COMMAND	AGE - 33	FLIGHT TIME (Hours)
CERTIFICATES/RATINGS		
Commercial, Airline transport		TOTAL ALL AIRCRAFT - 05120
Single-engine land, Multiengine land		LAST 90 DAYS - 00180
INSTRUMENT RATINGS		TOTAL MAKE/MODEL - 03000
Airplane		TOTAL INSTRUMENT TIME - 690

TURNING ONTO THE RWY THE COPLT OBSERVED A FLASH BEHIND HIS INST PANEL. HE THEN RECEIVED AN ELECT SHOCK TO HIS RIGHT ARM FROM THE RIGHT CONSOLE. A FIRE THEN ERUPTED AT THE LOWER RIGHT HAND CORNER OF HIS INST PANEL. THE CREW & PAX EVACUATED THE ACFT. THE INTERIOR OF THE ACFT WAS CONSUMED BY FIRE AS WELL AS MOST OF THE UPPER HALF OF THE FUSELAGE. EXAM OF THE RIGHT SIDE WIRE BUNDLE REVEALED NUMEROUS INDICATIONS OF ARCING BETWEEN WIRES & FROM WIRES TO GROUND. ONE WIRE WAS ARCED AT A POINT IN LINE WITH A PLASTIC OXYGEN LINE. THERE WAS ALSO AN OILY RESIDUE INSIDE THE WIRE BUNDLE. A SMALL SECTION OF THE RIGHT BRAKE PRESSURE LINE EXHIBITED SIGNS OF ELECT ARCNG. THE HYDRAULIC SYST PRESS GAGE COPPER LINE ALSO SHOWED SIGNS OF ARCING. THE PLASTIC OXYGEN LINES FROM THE COCKPIT SIDE OF THE FORWARD PRESSURE BULKHEAD TO THE COCKPIT OUTLETS HAD BEEN CONSUMED BY FIRE & THE OXYGEN SUPPLY WAS DEPLETED.

Occurrence# 1 FIRE
Phase of Operation TAXI - TO TAKEOFF

Findings

1. - FUSELAGE, INSTRUMENT/ELECTRICAL PANEL - SHORTED
2. - FUSELAGE, INSTRUMENT/ELECTRICAL PANEL - ARCING
3. - ELECTRICAL SYSTEM, ELECTRIC WIRING - ARCING
4. - ELECTRICAL SYSTEM, ELECTRIC WIRING - CONTAMINATION
5. - ELECTRICAL SYSTEM, ELECTRIC WIRING - FIRE
6. - OXYGEN SYSTEM, CREW - BURST
7. - FUSELAGE, INSTRUMENT/ELECTRICAL PANEL - FIRE
8. - FUSELAGE - FIRE

---Prophetic Causes---

CAUSES 1 2 3 4 5 6 7 8
FACTORS

National Transportation Safety Board
Washington, D.C. 20594

Brief of Accident

Adopted 09/19/1989

ANC88FA100
FILE NO. 1006 07/27/88
ANCHORAGE,AK
ICRAFT REG. NO. N482SA
TIME (LOCAL) - 18:17 ADT

MAKE/MODEL	- FAIRCHILD SA227-AT	CREW FATAL 0	SERIOUS 0	MINOR/NONE 2
ENGINE MAKE/MODEL	- GARRETT TPE-331-1146	PASS 0	0	6
AIRCRAFT DAMAGE	- Substantial			
NUMBER OF ENGINES	- 2			

OPERATING CERTIFICATES

- Commuter air carrier
- On-demand air taxi
- PENINSULA AIRWAYS
- Scheduled
- Domestic
- Passenger/cargo

REGULATION FLIGHT CONDUCTED UNDER - 14 CFR 135

LAST DEPARTURE POINT DESTINATION	- Same as Accident - DILLINGHAM,AK	CONDITION OF LIGHT - Daylight	WEATHER INFO SOURCE	- Weather observation facility
AIRPORT PROXIMITY AIRPORT NAME	- On airport	BASIC WEATHER	- Visual (VMC)	
RUNWAY IDENTIFICATION	- ANCHORAGE INT'L	LOWEST CEILING	- None	
RUNWAY LENGTH/WIDTH (Feet)	- 14	VISIBILIT	- 0060.000 SM	
RUNWAY SURFACE	- 10496/ 150	WIND DIR/SPEED	- 170/016 KTS	
RUNWAY SURFACE CONDITION	- Asphalt	TEMPERATURE (F)	- 63	
	- Dry	OBSTR TO VISION	- None	
		PRECIPITATION	- None	

PILOT-IN-COMMAND
AGE - 39

CERTIFICATES/RATINGS

- Airline transport
- Single-engine land, Multiengine land, Single-engine sea

FLIGHT TIME (Hours)	
TOTAL ALL AIRCRAFT	- 14800
LAST 90 DAYS	- 293
TOTAL MAKE/MODEL	- 2650

DURING THE TAXI TO THE RUNWAY, THE FLIGHT CREW NOTED A VIBRATION IN THE AIRPLANE AND STOPPED TO CHECK THE TIRES. THINKING THAT THEY WERE UNDERINFLATED. NO OBVIOUS PROBLEM WAS SEEN, AND THEY ELECTED TO TAKEOFF. SHORTLY AFTER TAKEOFF, A FIRE ERUPTED IN THE LEFT MAIN GEAR WHEELWELL. THE PILOT RETURNED TO THE AIRPORT AND LANDED SAFELY. HOWEVER, THE AIRPLANE SUSTAINED EXTENSIVE DAMAGE TO THE LEFT WING AND AILERON CONTROL SYSTEM. EXAMINATION OF THE BRAKES REVEALED A COCKED THERMAL INSULATOR IN THE PISTON BORE. THERE WAS EVIDENCE THAT THE BRAKES WERE WORN, HAD BEEN DRAGGING, THEN OVERHEATED; AND THAT THE TIRES HAD EXPLODED PRIOR TO THE FIRE. THE FIRE DAMAGE INDICATED THAT THE FIRE HAD STARTED NEAR THE BRAKES. AN ALUMINUM FITTING WAS USED AS PART OF THE HYDRAULIC BRAKE SYSTEM ON THE STEEL BRAKE HOUSING. THE EXAM INDICATED THAT THE FITTING HAD BEEN INSTALLED BUT COULD NOT BE FOUND AFTER THE FIRE. THE CREW SAID THAT THEY DELAYED LOWERING THE GEAR, IN CONTRADICTION TO THE CHECKLIST REQUIREMENT WHEN THE WHEELWELL AND WING OVERHEAT LIGHT IS ON.

AIRFRAME/COMPONENT/SYSTEM FAILURE/MALFUNCTION
TAXI - TO TAKEOFF

Findings

- 1. - LANDING GEAR, NORMAL BRAKE SYSTEM - BINDING(MECHANICAL)
- 2. - ACFT/EQUIP, INADEQUATE AIRCRAFT COMPONENT - MANUFACTURER
- 3. - PROPER ASSISTANCE - NOT OBTAINED - PILOT-IN-COMMAND

FIRE CLIMB Occurrence# 2 Phase of Operation

Einladung

4. - LANDING GEAR, NORMAL BRAKE SYSTEM - OVERTEMPERATURE
5. - HYDRAULIC SYSTEM, FITTING - MELTED
6. - EMERGENCY PROCEDURE - NOT FOLLOWED - PILOT-IN-COMMAND

—Prophäthe CanisP—

CAUSES 1 2 3 4 5
FACTORS 6

The Transportation Safety Board of Canada (TSB) investigated this occurrence for the purpose of advancing transportation safety. It is not the function of the Board to assign fault or determine civil or criminal liability.

AVIATION OCCURRENCE REPORT

PERIMETER AIRLINES
SWARINGEN SA226TC METRO II C-FGEP
WINNIPEG, MANITOBA
10 FEBRUARY 1990

REPORT NUMBER A90C0024

SYNOPSIS

The twin-engine turboprop aircraft, with two pilots and 11 passengers on board, departed Winnipeg International Airport on a regular scheduled flight to Island Lake, Manitoba. About 10 minutes north, while the aircraft was climbing to cruise altitude, the hydraulic system pressure started to fall. The pilot advised Winnipeg air traffic control that they were returning to the airport. The left main landing gear indicator lights then came on, showing both in-transit and down and locked. The pilots heard two loud bangs from the left side of the aircraft, and the captain feathered the left engine. On final approach, a manual landing gear extension was completed, and the tower controller advised the pilot that the left landing gear was not visible, and that the left engine was on fire. The pilot carried out an emergency landing, and all the occupants evacuated the aircraft safely.

The Transportation Safety Board of Canada determined that an overheated left inner brake ignited the left main landing gear tires, and that the fire was fuelled by a leaking fuel pressure line in the left wheel well.



National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: November 30, 1998

In reply refer to: A-98-119 through -121

Honorable Jane F. Garvey
Administrator
Federal Aviation Administration
Washington, D.C. 20591

On April 11, 1997, the pilot of a single-seat Glaser-Dirks DG-300 glider, N70644, was killed after he lost control of the aircraft for undetermined reasons and crashed near Minden, Nevada. The National Transportation Safety Board's investigation found that the pilot had jettisoned the glider's canopy in an apparent attempt to parachute from the aircraft but that he was subsequently incapacitated when the canopy struck his forehead during the jettison sequence (the basis for these findings is discussed later in this letter). As a result, he remained with the aircraft and was found in the cockpit with his seat belt restraint system still fastened. The nearly horizontal flightpath of the jettisoned canopy caused it to strike the glider's T-tail, become impaled on the horizontal portion of the T-tail, and remain with the aircraft until ground impact. The glider was destroyed.

The canopy's emergency jettison release knob and pin-latch handle had both been pulled in accordance with the requirements for jettisoning outlined in the DG-300 Pilot's Operating Handbook. The handbook indicates that the jettisoned canopy will then be blown away by the oncoming airstream.

In normal operation, the canopy is latched or unlatched at the aft end, and the front end of the canopy pivots about an airframe-mounted pivot assembly. Pulling the canopy's pin-latch handle withdraws the pin from the latch clevis and unlocks the canopy at the aft end. The canopy's latching pin, on the aft upper part of the canopy, and the latch clevis, on the aft upper part of the cockpit, were found intact and undamaged. Pulling the jettison release knob unlocks the front end pivot assembly and allows a small spring to push the front end of the canopy upward, away from the pivot plate. The Safety Board found that activating the release knob on the ground results in a positive release of the canopy from the pivot plate. However, the spring force does not result in significant upward travel of the front end of the canopy and, therefore, may be insufficient to ensure automatic in-flight separation of the canopy from the fuselage.

The left and right outboard horizontal sections of the glider's T-tail contained impact marks with black paint smears similar to the black paint on the interior of the canopy frame; the distance between the impact marks approximated the length of the canopy frame. There were several small punctures on the upper surface of the tail; one was round with red material, approximating the shape and color of the jettison release knob. Pieces of the canopy Plexiglas were found up to 300 yards from the glider's main wreckage.

According to the autopsy report, the pilot's face had several large lacerations and abrasions with minimal associated hemorrhage. No blood was observed anywhere on the pilot's face, but the autopsy report described a large bruise on the forehead as follows: "Covering the front of the forehead, almost paralleling the eyebrows, is a 10.0 x 6.0 cm area of confluent purple-gray abrasion superimposing contusion." This was the only contusion¹ noted anywhere on the pilot's head. The contusion was consistent with impact from a solid, hard object with a linear edge. The absence of bleeding, despite large lacerations to the pilot's face, indicates that his death upon ground impact was abrupt, resulting from blunt force trauma.

The contusion (bruise) on the pilot's forehead, however, required a finite period of time after the trauma was inflicted for the injury to accumulate blood. Moreover, blood to this area of the body could not have resulted from gravity flow but had to be provided under pressure. Therefore, the impact force causing the contusion had to have been inflicted before the ground impact that killed the pilot. This fact, together with the shape and location of the contusion, provides compelling evidence that the canopy frame struck the pilot on the forehead during the jettison sequence.

The DG-300 is manufactured in Germany by DG Flugzeugbau GmbH and is type certificated in that country in the utility category, according to Joint Airworthiness Requirements for Sailplanes and Powered Sailplanes (JAR-22).² However, the glider has not been type certificated in the United States but is currently imported, licensed, and operated in the experimental category. According to the manufacturer, jettison of the DG-300 canopy or the canopies on DG-100/200/400/600 series gliders (aircraft configured with a similar canopy and jettison mechanism) was not required to be demonstrated during the course of German certification. However, the manufacturer indicated that, during a flight test of a DG-600, jettison of the canopy became necessary during a spiral dive and was accomplished successfully without injury to the pilot.

Egress from the cockpit and jettisoning of the canopy are addressed in the following excerpts from JAR 22.807, Emergency Exit:

¹ A contusion (bruise) signifies hemorrhage into the skin, the tissues under the skin, or both. It is usually the result of a blow or squeeze that crushes the tissues and ruptures blood vessels but does not break the skin.

² JAR-22 is based on the Federal Republic of Germany's national airworthiness code and was developed through the joint participation of several European countries.

- (a) The cockpit must be so designed that unimpeded and rapid escape in emergency situations during flight and on the ground is possible with the occupant wearing a parachute.
- (b) The opening, and where appropriate jettisoning, of each canopy or emergency exit must not be prevented by the presence of the appropriate aerodynamic forces and/or the weight of the canopy at speeds up to V_{df} or by jamming of the canopy with other parts of the sailplane. The canopy or emergency exit attachment fittings must be designed to permit easy jettisoning, where jettisoning is a necessary feature of the design.

Until recently, all Glaser-Dirks gliders imported into the United States, except for the DG-500 model, were certificated in the experimental category. However, the DG-100/400/500/800 models are now type certificated in the standard (utility) airworthiness category, and the Safety Board understands that the Federal Aviation Administration (FAA) has initiated a program aimed at eventual type certification of all Glaser-Dirks gliders in the standard airworthiness category. Even though the Safety Board concurs with the FAA's certification objectives, it is concerned about the extent to which jettison of the canopies of these gliders has been demonstrated for certification purposes. Although the jettison of a DG-600 canopy was apparently accomplished without incident, the Safety Board does not believe that this single event provides a sufficient technical basis for concluding that the canopy can be jettisoned successfully under all conditions throughout the complete airspeed and maneuver operating envelopes of these gliders. For example, flight at high angles of attack or sideslip, as in a spin, might significantly affect a canopy's jettison characteristics and its subsequent flightpath.

In connection with an evaluation of existing glider canopy jettisoning systems, the German Federal Ministry of Transport commissioned the 1991 study "Problems and Improvements of Canopy Jettisoning Systems" in which tests were performed with a glider mounted on the roof of an automobile. Details were presented of the motion and flightpath of the canopy, after its release in an emergency, as well as the influence of airspeed, angle of attack, sideslip, and raising of the front end of the canopy. The study concluded the following:

It is clear that none of the existing mechanisms in today's gliders guarantee a problem-free jettisoning of the canopy and there is a high risk of injury to the pilot by the moving canopy. The main reason for this is the nose-down pitching and nose-inwards yawing moment on the canopy. This is due to the position of the center of pressure which is behind the center of gravity. This nose-down moment can be transformed into a nose-up pitching moment by a rear hinge between the top of the canopy and the fuselage. This hinge can take the form of a simple clasp. In such cases, the hinge must be released at an angle of approximately 40 degrees between the canopy and the cockpit. This simple improvement means that after the release, the canopy rotates with a nose-up pitching moment, separates quickly

from the cockpit and passes high above the rudder. There is no risk of injury to the pilot.

An automatic jettisoning assumes a raising of the front part. At low speeds and a low angle of attack, the raising does not initiate the separation of the canopy. For this reason, there should be two handles on the right and left frame of the canopy which the pilot can use to assist jettisoning. These handles should also be used to release the canopy. This is why there should be two handles in any canopy jettisoning system.

The relatively shallow, almost horizontal flightpath of the jettisoned canopy from N70644, causing it to strike both the pilot and the glider's T-tail, contrasts sharply with the study's test results based on a canopy with a rear hinge that releases from the cockpit at about 40°. For example, in one such test conducted at 70 knots, the canopy rotated upward around the hinge, separated from the fuselage at the proper angle, ascended steeply, and passed over the glider's tail at a height of about 13 feet.

There are about 88 aircraft of the DG-300/400/500/600/800 series currently operating in the United States. The Safety Board believes, based on the FAA's program to eventually certificate all Glaser-Dirks gliders in the standard airworthiness category, that the models and their numbers may increase significantly. Therefore, the Safety Board believes that the FAA should require DG Flugzeugbau GmbH to conduct testing of the canopy jettison system used on all Glaser-Dirks gliders certificated in the United States to determine the design changes, conditions, or limitations necessary to ensure that the canopies can be reliably jettisoned throughout the airspeed and maneuver operating envelopes of the aircraft without striking the pilot. The Safety Board also believes that the FAA should issue an airworthiness directive, applicable to all Glaser-Dirks gliders certificated in the United States in the standard airworthiness category, requiring the implementation of any appropriate design changes and/or operational procedures. Further, The Board believes that the FAA should issue a special airworthiness information bulletin, applicable to all Glaser-Dirks gliders certificated in the United States in the special (experimental) airworthiness category, advising owners of the need to implement any appropriate design changes and/or operational procedures.

Therefore, the National Transportation Safety Board recommends that the Federal Aviation Administration:

Require DG Flugzeugbau GmbH to conduct testing of the canopy jettison system used on all Glaser-Dirks gliders certificated in the United States to determine the design changes, conditions, or limitations necessary to ensure that the canopies can be reliably jettisoned throughout the airspeed and maneuver operating envelopes of the aircraft without striking the pilot. (A-98-119)

Issue an airworthiness directive, applicable to all Glaser-Dirks gliders certificated in the United States in the standard airworthiness category, requiring the implementation of any appropriate design changes and/or operational procedures. (A-98-120)

Issue a special airworthiness information bulletin, applicable to all Glaser-Dirks gliders certificated in the United States in the special (experimental) airworthiness category, advising owners of the need to implement any appropriate design changes and/or operational procedures. (A-98-121).

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in these recommendations.

By: 
Jim Hall
Chairman



National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: November 30, 1998

In reply refer to: A-98-122 through -124

Honorable Jane F. Garvey
Administrator
Federal Aviation Administration
Washington, D.C. 20591

On June 2, 1998, a Boeing 757-232 (B-757), N629DL, owned and operated by Delta Airlines, Inc., was damaged when its left off-wing emergency evacuation slide separated from the airplane during a scheduled flight operated under Title 14 Code of Federal Regulations Part 121 en route from LaGuardia Airport (LGA) to Cincinnati/Northern Kentucky International Airport (CVG). The pilot reported that during climbout from LGA he noticed the engine indication and crew alerting system (EICAS) light illuminate, indicating that the left off-wing slide door was open. The flight continued to CVG and landed without further incident. None of the occupants were injured.

After the airplane landed, a Delta Airlines mechanic performed a walk-around inspection. During the inspection he saw that the left off-wing emergency escape slide had separated from the airplane, the left side of the fuselage aft of the slide was damaged, the slide was missing, and the restraining hook that mounted to the slide platform was broken, which allowed the platform to over-rotate, causing damage to the wing and fuselage (see figure 1). The slide carrier, the platform, and the door latching tube remained with the airplane. Further inspection found significant damage to the left side of the fuselage aft of the trailing edge of the left inboard flap.

During its investigation of the B-757 off-wing escape slide, the National Transportation Safety Board found that Delta Airlines had performed a replacement of the left off-wing emergency escape slide 2 days before the incident. The two mechanics who replaced the slide stated that it was the first time they had replaced a B-757 off-wing slide. The mechanics stated that they referred to the B-757 maintenance manual, sections 25-65-00 and 25-65-01, and the placard on the inside of the maintenance access door while they replaced the slide.¹ One mechanic maneuvered the round yellow actuator handle that secures the off-wing emergency slide door within the slide compartment (see figure 2), and the other mechanic held the slide door closed (by sitting on the wing and pressing on the door with both his feet.) The mechanic who manipulated the round yellow actuator handle said it was difficult to ensure that the handle was in the full-

¹ Section 25-65-00 describes the operation of the B-757 off-wing escape system, and 25-65-01 describes the removal/installation of the B-757 off-wing escape slide pack.

down position, stating that "it took several attempts to move the actuator handle to the latched position." The mechanics stated that after the door was latched one mechanic ran his finger around the door to ensure it was closed, and then both mechanics checked the EICAS in the cockpit to ensure that the door was closed. One of the two mechanics said that he had received instructions on how to replace the slide about 4 or 5 years ago during a 2-week B-757 initial maintenance training class that provided instructions on all B-757 systems. The other mechanic had not yet received training on the B-757 off-wing escape slide replacement during his 3 months of employment at Delta.

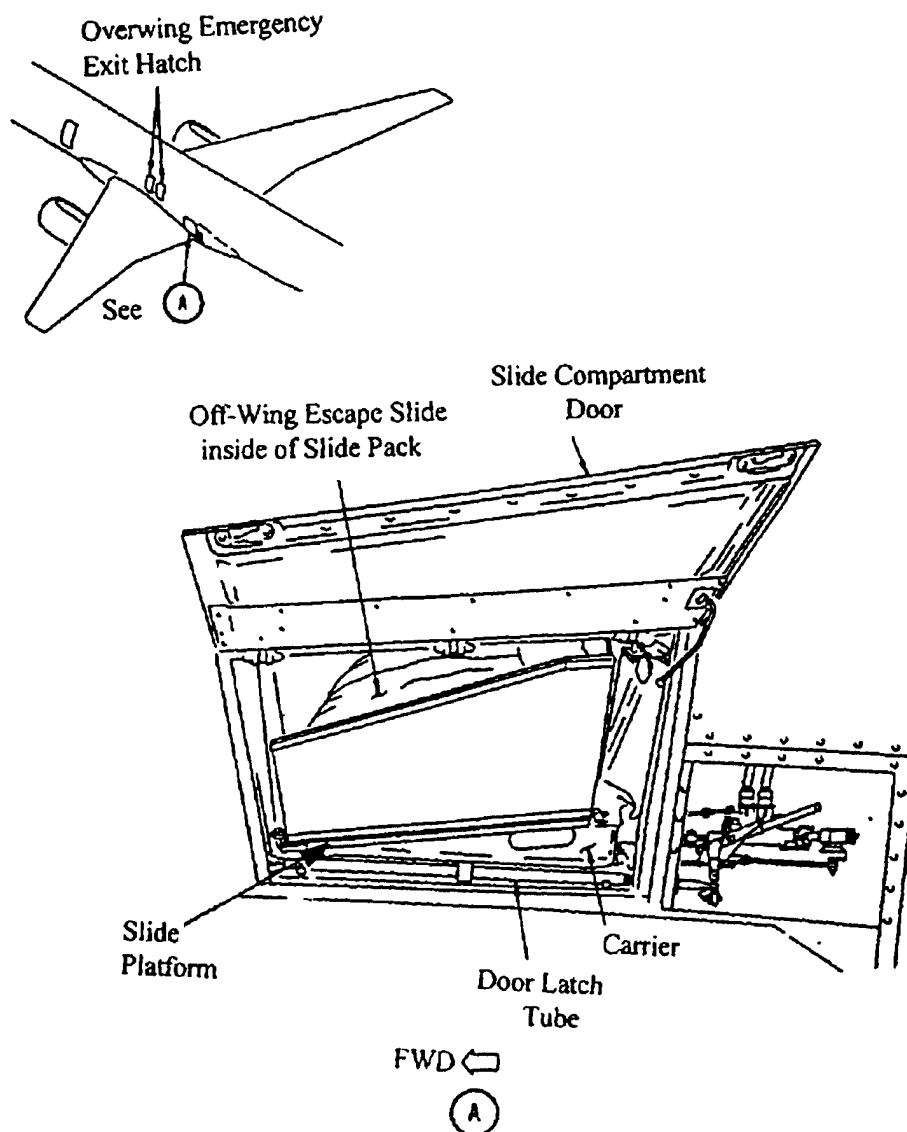


Figure 1.—B-757 Off-Wing Escape Slide Assembly

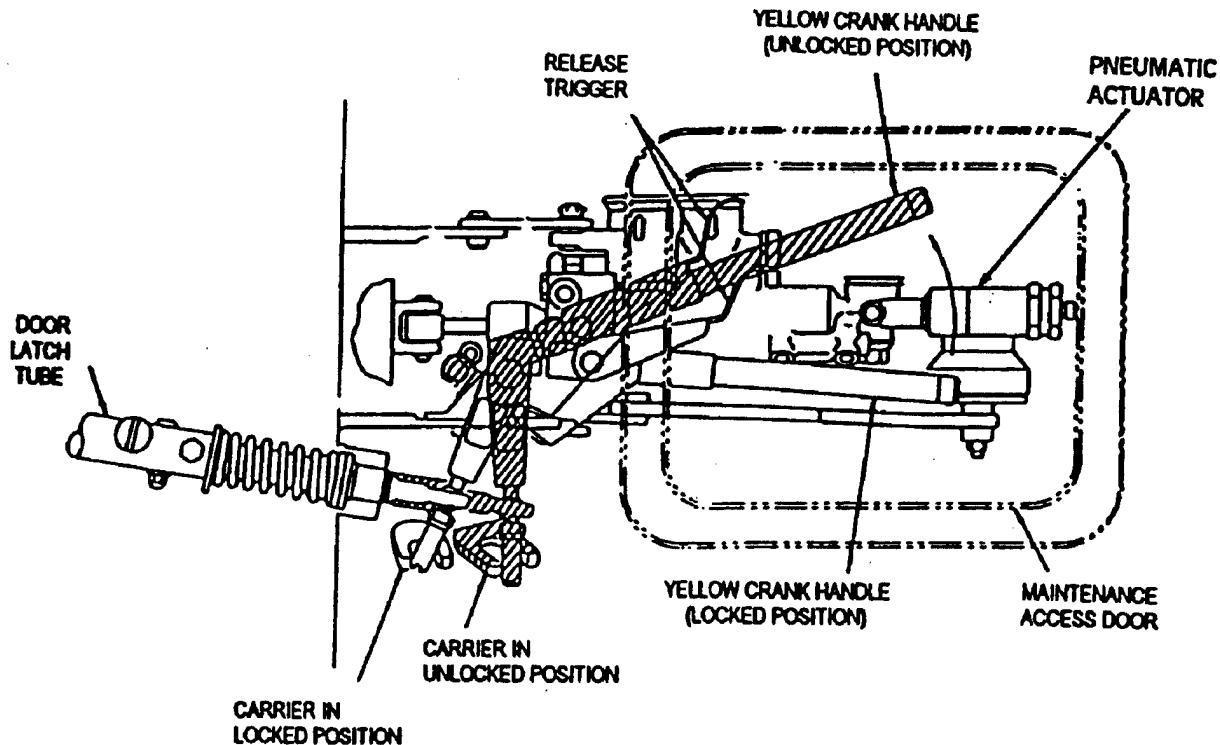


Figure 2.—B-757 Off-Wing Escape Slide Actuator Assembly

Previous In-flight Separations of Off-Wing Emergency Escape Slides

On October 16, 1997, a B-757, operated by United Airlines, Inc., was damaged when its left off-wing emergency evacuation slide separated from the airplane during a scheduled flight en route from Seattle, Washington, to Denver, Colorado. The captain stated to Safety Board investigators that as the airplane was rotated for liftoff, he noticed the EICAS light illuminate, indicating that the left wing slide door was open. The flight continued to Denver International Airport (DIA), and during its descent for landing, a flight attendant who was in the midcabin heard a loud noise on the left side of the airplane. The airplane landed without further incident at DIA, and none of the occupants were injured.

The Safety Board's investigation found that United had performed a routine replacement of the left off-wing emergency escape slide the evening before the incident. One of the two mechanics who replaced the slide that evening stated that it was only the second time in his 12-

year career with the airline that he had replaced a B-757 off-wing slide. He had replaced the first slide about 10 years earlier. The mechanic stated that when he replaced the slide the night before the incident, he had been outdoors (on the ramp) using a flashlight and had referred to the B-757 maintenance manual. The mechanic stated that he was not aware that there were instructions (which indicated the proper positioning of the yellow actuator handle that secured the off-wing emergency slide door within the slide compartment) on a placard inside the maintenance access door. The mechanic also stated that he had not received any formal training from Boeing or from United for installing the off-wing escape slide system and that he relied solely on the B-757 maintenance manual. The other mechanic stated that this was the first time that he had replaced a B-757 off-wing escape slide. He said that he had not received training on the B-757 off-wing escape slide replacement during his 11 years of employment at United.

On June 8, 1993, a B-757 left off-wing emergency escape slide deployed while United Airlines flight 382 was climbing through flight level 250. The captain heard an "explosive noise" followed by the airplane rolling sharply to the left.² The flightcrew declared an emergency and made an uneventful landing at Los Angeles International Airport, Los Angeles, California. A postincident inspection found that the left off-wing escape slide had deployed and had separated (at an unknown time) in flight. The Safety Board's investigation of the incident found that United had performed maintenance on the left off-wing escape slide before the flight.

Information on Servicing and Replacing the Off-Wing Emergency Escape Slide

The B-757 off-wing emergency escape slide system is located just above the trailing edge of each wing in the aft wing/body fairing and consists of a ramp/slide folded into a "slide pack" attached to a packboard and installed on a carrier assembly. To service the slide, a mechanic must first open the slide maintenance access door and release the trigger on a round yellow handle. The yellow handle actuates a pneumatic actuator, which unlatches the slide compartment door. The slide compartment door is locked in the closed position by lowering the yellow handle to its lowest position; this secures the door latch tube that is located along the lower edge of the slide compartment (see figure 2). A door sensor (micro switch) located on the aft edge of the door sill activates the "EMER DOORS" light on the cockpit overhead annunciator panel and displays the "L WING SLIDE" or "R WING SLIDE" EICAS message if either off-wing slide door opens more than 0.24 inch at its sensor switch.

Replacement of the slide requires that a mechanic remove the main landing gear wheel well access cover located directly beneath the slide carrier compartment to remove the bolts that secure the slide pack to the carrier. Also, the carrier has a locking pin that can only be viewed by a mechanic from the lower wheel well. When the slide's carrier is fully locked in place and the yellow crank handle is moved to the down and locked position, the locking pin should be fully engaged in the carrier's locking lug. The maintenance manual provides step-by-step guidance for the removal and installation of the B-757 off-wing emergency escape slide, and section 25-65-09

² For more detailed information, read Brief of Incident LAX93IA245 (enclosed).

recommends, "Push the handle down to its lowest position while you push inboard on the carrier to make sure the carrier is locked in the inboard position."

In-Service Activities Report and Service Bulletin History Regarding B-757 Off-Wing Escape Slides

In its September 14, 1993, B-757 In-Service Activities Report (SAR) No. 93-17, Boeing alerted operators of B-757s with off-wing slides (part number 93-17-2565-00) of the June 8, 1993, incident.³ The SAR stated that the fuselage's paint had been scuffed in several large areas aft of the slide compartment door and on the leading edge of the left horizontal stabilizer. The SAR further stated that the aft latch of the airplane's left off-wing escape slide compartment door was only partially engaged, allowing the forward edge of the compartment door to open in the air stream and then to flex further into the air stream until it was forced open. The SAR further revealed that after the door had opened, the escape slide's carrier freely rotated out of its compartment, the slide release pin was pulled, and the escape slide unpacked and tore free from its packboard. Finally, the SAR stated that the B-757 maintenance manual's section 25-65-09 would be updated on September 20, 1993, to incorporate slide access door placard instructions and to clarify maintenance procedures for closing and properly locking the off-wing slide door.

On October 10, 1996, Boeing issued Service Bulletin (SB) 757-25-0182 to all operators of B-757 airplanes with off-wing escape slide systems through airplane production line position 727 (the 727th B-757 produced). The SB reported that two additional incidents had occurred since June 1993 in which air carrier operators had experienced the separation in flight of an off-wing emergency escape slide that resulted in damage to the airplane fuselage aft of the slide compartment.⁴ All three incidents had occurred following maintenance. The SB stated that Boeing's analysis of the off-wing slide separations found three problems that induced the separations:

- difficulty in visually inspecting the forward edge of the slide compartment door to ensure that it is correctly latched,
- the aft location of the door's electrical sensor may not clearly indicate whether the forward edge of the slide compartment door is latched, and
- the incorrect installation of the lockbase retainer on the door latch tube, which can prevent locking the door latch tube in the latched position.

To remedy these problems, the SB provided instructions to replace the lockbase retainer and the bearing for the door's latch tube and to relocate the door's sensor forward on the slide compartment door.

³ About 50 percent of the B-757 airplanes manufactured by Boeing are equipped with off-wing emergency escape slides.

⁴ The two previous B-757 off-wing emergency escape slide incidents involved separations of right off-wing slides on a Continental Airlines B-757 on September 25, 1995, and a Boeing flight test B-757 airplane on November 15, 1995.

Since Boeing issued SB 757-25-0182, three other in-flight B-757 off-wing emergency escape slide separations have occurred following maintenance of the slides: the Delta Airlines N629DL on June 2, 1998; the United Airlines N581UA on October 16, 1997; and one involving an American Airlines B-757 on June 24, 1997. These airplanes had not been modified as directed by SB 757-25-0182. American Airlines subsequently painted a red stripe on the B-757 off-wing escape slide compartment door frames to help mechanics determine when the slide compartment door is properly positioned and latched.

On November 13, 1997, subsequent to the United and American separations, Boeing issued All-Operator Message M-7272-97-5654 to advise B-757 operators of the importance of incorporating SB 757-25-0182. The message informed operators of the importance of incorporating the SB at their earliest opportunity, of placing a new decal on the inside of the access door, of placing a paint stripe or tape on the lip of the maintenance access door (to show proper alignment and the locked position of the round yellow crank handle), and of removing the access panel from the container shroud in the main gear wheel well while a mechanic visually inspects that the carrier latch pin is fully engaged with the lock carrier fitting. Boeing reported that on May 20, 1998, the contents of the All-Operator Message were incorporated into its maintenance manuals.

The Safety Board commends all of the efforts made by Boeing; however, the Board is concerned that because these measures are not mandatory some operators may not perform the actions set forth in the SB. Therefore, the Safety Board believes that the Federal Aviation Administration (FAA) should issue an airworthiness directive (AD) to make compliance with Boeing SB 757-25-0182 mandatory to reduce the current potential for in-flight separation of the off-wing escape slides.

In a June 30, 1998, letter to the Safety Board, Boeing stated that it was designing the following three new system enhancements for the B-757 off-wing escape slides:

- 1.) installation of a bumper on the slide pack carrier to ensure it is pushed in far enough to be locked in place and to prevent movement of the carrier before actuation of the yellow crank handle,
- 2.) the addition of a witness mark on the lip of the maintenance access door frame that aligns with the yellow crank handle to ensure the handle is in the locked position, and
- 3.) the rewriting of the instructions on the placard on the inside of the maintenance access door to provide clear, concise direction to ensure the door is faired and latched prior to flight.

Boeing further reported that the three system enhancements are currently in the design phase and will be incorporated into the B-757 production line in December 1998. Boeing proposed that the B-757 fleet retrofit will be handled by a SB that will incorporate all three

enhancements. Therefore, as a further safety measure, the Safety Board believes that the FAA should, upon release of the SB that incorporates the B-757 off-wing escape slide system enhancements currently in work by Boeing, issue an AD to mandate the incorporation of the improvements.

The Safety Board is concerned that mechanics may not be aware of Boeing's recently completed and proposed system enhancements on the B-757 off-wing escape slides. Further, because the B-757 off-wing escape slides are not frequently serviced or replaced, updated training would acquaint the mechanics with the recent changes and improvements to the B-757 off-wing escape slide system. Therefore, the Safety Board believes the FAA should issue a flight standards information bulletin to require that principal maintenance inspectors ensure that all mechanics are trained on the new off-wing escape slide system enhancements on the B-757.

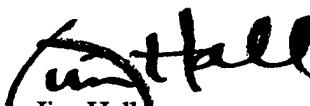
Therefore, the National Transportation Safety Board recommends that the Federal Aviation Administration:

Issue an airworthiness directive to make compliance with Boeing Service Bulletin 757-25-0182 mandatory to reduce the current potential for in-flight separation of the off-wing escape slides. (A-98-122)

Upon release of the service bulletin that incorporates the B-757 off-wing escape slide system enhancements currently in work by Boeing, issue an airworthiness directive to mandate the incorporation of the improvements. (A-98-123)

Issue a flight standards information bulletin to require that principal maintenance inspectors ensure that all mechanics are trained on the new off-wing escape slide system enhancements on the B-757. (A-98-124)

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in these recommendations.

By: 
Jim Hall
Chairman

Enclosure

National Transportation Safety Board
Washington, D.C. 20594

Brief of Incident

Adopted 08/01/1994

LAX931A245

FILE NO. 5028

06/08/93

LOS ANGELES, CA

AIRCRAFT REG. NO. N540UA

TIME (LOCAL) - 10:59 PDT

MAKE/MODEL	- BOEING 757-222
ENGINE MAKE/MODEL	- P & W 2037
AIRCRAFT DAMAGE	- Minor
NUMBER OF ENGINES	- 2

OPERATING CERTIFICATES

- Flag carrier/domestic
- UNITED AIRLINES
- Scheduled
- Domestic
- Passenger

REGULATION FLIGHT CONDUCTED UNDER - 14 CFR 121

LAST DEPARTURE POINT - Same as Incident
DESTINATION - DENVER, CO

AIRPORT PROXIMITY - Off airport/airstrip

CONDITION OF LIGHT - Daylight
WEATHER INFO SOURCE- Pilot

BASIC WEATHER	- Visual (VMC)
LOWEST CEILING	- None
VISIBILITY	- 0050.000 SM
WIND DIR/SPEED	- Unk/NR
TEMPERATURE (F)	- Unk/NR
OBSTR TO VISION	- None
PRECIPITATION	- None

PILOT-IN-COMMAND AGE - 58

CERTIFICATES/RATINGS

Airline transport

Single-engine land, Multiengine land

INSTRUMENT RATINGS

Airplane

FLIGHT TIME (Hours)

TOTAL ALL AIRCRAFT	- 18400
LAST 90 DAYS	- Unk/NR
TOTAL MAKE/MODEL	- Unk/NR
TOTAL INSTRUMENT TIME	- Unk/NR

The aircraft was climbing through 25,000 feet in light turbulence when the crew felt two jolts and heard a loud explosive noise followed by a sharp roll to the left. A visual inspection revealed that the left overwing emergency escape slide deployed and separated in flight. The crew returned to Los Angeles and made an uneventful landing. Post incident examination revealed that the slide compartment door was unlatched and open, and the adjacent maintenance access door was open, with the latching handle in the unlocked position. The flight prior to the incident one had experienced two EICAS warning messages concerning the left overwing slide door. After landing, maintenance personnel accessed the compartment, cleaned a proximity switch then functionally tested the system. The flight was then dispatched with no open items. The maintenance closing procedure in effect at the time of the incident called for one mechanic to

hold the bottom corners of the 33 inch wide slide door closed while manipulating the latching handle in a maintenance access door 12 inches aft of the slide door. The procedure has since been changed to require two mechanics, one to hold the door closed while the second manipulates the latching handle.

Brief of Incident (Continued)

LAX93IA245
FILE NO. 5028 06/08/93 LOS ANGELES, CA AIRCRAFT REG. NO. N540UA TIME (LOCAL) - 10:59 PDT

Occurrence# 1 MISCELLANEOUS/OTHER
Phase of Operation CLIMB - TO CRUISE

Findings

1. - MISC EQPT/FURNISHINGS, SLIDES - UNLATCHED
2. - MAINTENANCE ALIGNMENT - INADEQUATE - COMPANY MAINTENANCE PERSONNEL
3. - PROCEDURE INADEQUATE - MANUFACTURER

The National Transportation Safety Board determines that the probable cause(s) of this incident was: the inadvertent deployment of an overwing emergency escape slide due to the inadequate latching of the slide compartment door following access by maintenance personnel. A factor in the accident was the inadequate door closing procedure specified by the manufacturer and the airline in the maintenance instructions.



National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: December 3, 1998

In reply refer to: A-98-125 and -126

Honorable Jane F. Garvey
Administrator
Federal Aviation Administration
Washington, D.C. 20591

On December 6, 1995, Pakistan International Airlines (PIA) flight 722, a Boeing 747-240 "Combi" airplane,¹ experienced an uncontained failure² in the low pressure turbine (LPT) area of the No. 2 engine, a General Electric Aircraft Engines (GE) CF6-50E2, shortly after takeoff from John F. Kennedy International Airport (JFK), New York.³ The flightcrew reported that as the airplane was climbing through 1,000 feet, they heard a loud thud and grinding noise and that the airplane then yawed to the left. The flight engineer reported that immediately after he heard the thud, he noted that the No. 2 engine oil pressure and oil quantity gauges were both indicating zero. The flightcrew continued the climb and later shut down the No. 2 engine. The airplane returned to JFK and landed without further incident. None of the 240 passengers and 15 crewmembers on board were injured. The airplane was operating on an instrument flight rules (IFR) flight plan under the provisions of Title 14 Code of Federal Regulations (CFR) Part 129 as a regularly scheduled international passenger and cargo flight from JFK to Charles de Gaulle Airport, Paris, France.

The examination of the No. 2 engine revealed that most of the LPT module was missing (see figure 1). The airplane had punctures to its left wing leading edge slats and to a landing gear door. In addition, the No. 1 engine had hard body impact damage⁴ to 18 of the 38 fan blades, and the fan cowl had impact damage from the debris ejected from the No. 2 engine.

¹ A Boeing 747 Combi airplane is configured such that it can carry both passengers and cargo on the main deck.

² An uncontained engine failure occurs when an internal part of the engine fails and is ejected, or results in other parts being ejected, through the cowling.

³ For more detailed information, see Brief of Incident NYC96IA036 (enclosed).

⁴ Hard body impact damage is characterized by a serrated appearance and deep cuts to the airfoil's leading and trailing edges. Hard body impact damage can result from impact with metal parts, concrete, asphalt, and rocks.

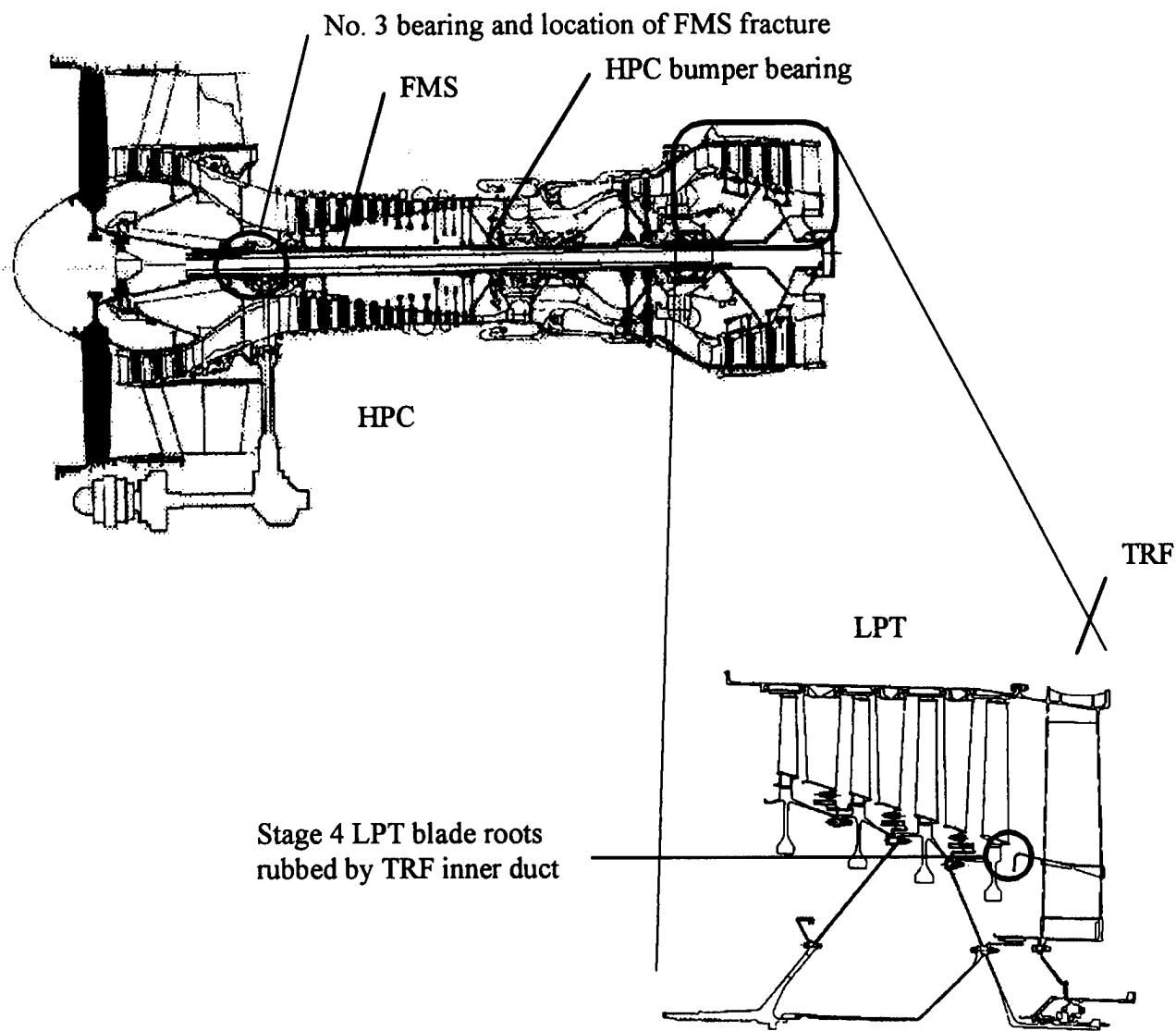


Figure 1. Cross section of CF6-50 engine and expanded view of LPT module

Disassembly of the engine, serial number (SN) 455-954, at GE's Engine Maintenance Center, Ontario, California, under the direction of the National Transportation Safety Board, revealed that the fan midshaft (FMS) was fractured circumferentially, just aft of the No. 3 (roller) bearing. Although the No. 3 bearing was damaged, the damage was typical of secondary damage that would have occurred late in the engine failure sequence.

Examination of the fractured FMS by the Safety Board's and GE's materials laboratories revealed a fatigue fracture with multiple origins on the outer diameter (OD) of the shaft that propagated inward. The examinations also revealed a color variation across the fracture surface and a reduction of the material hardness at the fracture in comparison to the other areas of the FMS and the engineering drawing specification, indicating that the part had been previously

overheated. In addition, SerMetel paint⁵ was found on the surface of the fatigue fracture, suggesting that the crack existed but was not detected when the shaft had been painted following a previous repair.

The maintenance records for the fractured FMS, part number 9032M21P18, SN MPOE3573, show that it had been installed in another PIA CF6-50 engine, SN 455-927, which was brought into PIA's engine shop on September 26, 1986, because of a No. 3 bearing failure. The records show that the FMS was overhauled, magnetic particle inspected (MPI),⁶ hardness checked in Area B,⁷ dimensionally inspected, and painted. At the time of the No. 3 bearing failure in PIA engine SN 455-927, the FMS had 4,594 cycles since new (CSN). The fracture occurred 9,235 cycles later at 13,829 CSN. The records also show that PIA overhauled, conducted an MPI, and painted the FMS on August 12, 1991, at 9,764 CSN, 4,065 cycles before the fracture; and on December 14, 1993, at 12,292 CSN, 1,537 cycles before the fracture. There was no record that the FMS had been inspected by etching the surface,⁸ as required by the CF6-50 Shop Manual⁹ if the shaft had been rubbed.¹⁰

The Safety Board is concerned about the potential for other FMS fractures from rubs sufficient to overheat the material and reduce its tensile and fatigue properties but not sufficient to cause damage warranting an inspection of the shafts. However, the Safety Board notes that as a result of the PIA investigation, GE issued Alert Service Bulletin CF6-50 72-A1120 on April 4, 1997, which identifies other CF6-50 FMSs that had been rubbed and provides a one-time eddy current inspection procedure to identify and remove from service any FMSs that were overheated.

The disassembly of the PIA engine showed that the center section of the FMS had become wedged into the high pressure compressor (HPC) bumper bearings. The design of the CF6-50 engine's FMS is such that the OD of the forward half of the shaft is greater than the inner diameter of the bumper bearing on the inside of the HPC rear hub. On the PIA engine, when the FMS fractured at its forward end, the rear section moved aft, and the larger diameter section of the shaft became wedged into the bumper bearing, limiting the rearward movement of the LPT

⁵ SerMetel paint is an aluminum-based corrosion preventative coating.

⁶ MPI is a nondestructive method of detecting cracks and other defects in ferromagnetic materials such as iron or steel. The inspection consists of magnetizing the part with high-amperage, direct current electricity, thus creating magnetic lines of flux, then applying or immersing the part in a liquid containing ferromagnetic particles in suspension. The ferromagnetic particles align themselves with the magnetic lines of flux on the surface of the part forming a pattern. If a discontinuity is present in the material on or near the surface, opposing magnetic poles form on either side of the discontinuity and the pattern is disrupted, forming an "indication." The indications assume the approximate size and shape of the surface projection of the discontinuity; however, indications are more visible when the defects are approximately perpendicular to the magnetic lines of flux.

⁷ Area B is on the forward section of the FMS, away from the area of the fracture.

⁸ Etching the surface is a nondestructive test procedure that will show if the base metal has been locally overheated because of a rub.

⁹ GE CF6-50 Task Numbered Shop Manual, Inspection, Subtask 72-24-01-220-053.

¹⁰ The No. 3 bearing supports and aligns the forward end of the FMS. When the bearing fails, the FMS shifts slightly, allowing contact with the HPC disk bore causing rubbing and frictional overheating. In the PIA event, the rub on the FMS would have been evident when it was repaired in 1986 after the No. 3 bearing failure. Since the FMS was painted in 1986, after the No. 3 bearing failure, the rub damage would not have been evident during subsequent inspections.

rotor. With the FMS wedged into the bumper bearing, the LPT rotor was then driven by the high pressure rotor, which has a rotational speed more than twice the rpm limit of the low pressure rotor. Additionally, two stage 4 LPT blade roots recovered from the core cowl had circumferential grooves on their rear faces. The grooves corresponded to the forward edge of the turbine rear frame (TRF) inner duct, indicating that additional structure had limited the rearward movement of the LPT rotor and meshing¹¹ action, thus permitting the rotor to overspeed. Several stage 1 LPT blades recovered from the wing slat area were rubbed on the rear faces of their roots and had the rear portions of the blade root serrations sheared consistent with the radial outward movement of the blades, suggesting that those blades were pushed out of the disk from the rear and separated under high-centrifugal loads.

On February 22, 1996, a Continental Airlines McDonnell Douglas DC-10 airplane sustained uncontained LPT damage to the No. 3 engine, a CF6-50C2, because of an FMS fracture during the takeoff roll at Houston, Texas. The flightcrew reported that when they heard the engine surge,¹² they immediately retarded the power levers to idle and rejected the takeoff. The engine's core cowl was penetrated by turbine blade fragments, but no damage to any other part of the airplane occurred. The examination of the Continental Airlines engine showed that the FMS had fractured near the forward end after being rubbed by the HPC air duct, which had fractured circumferentially along the seam of a previous weld repair because of porosity in the weld. The examination also revealed that the FMS had become wedged into the HPC bumper bearing, and the stage 4 LPT blades were rubbed on their rear faces, much like on the PIA engine.

GE reported that a dimensional inspection of the LPT disks showed that the disks had "grown," indicating that the LPT rotor had accelerated to 140 percent rpm.¹³ The Safety Board is concerned about the LPT rotor overspeeds and uncontained LPT damage that occur even when the flightcrew promptly retards the engine power, as was done by the Continental Airlines flightcrew. The Safety Board is further concerned about the extent of resultant damage when an FMS fracture occurs and the flightcrew cannot immediately reduce power on the affected engine, such as on the PIA flight. The rubs on the rear faces of the stage 4 LPT blade roots and the wedging of the FMS into the HPC bumper bearing, which were noted on the PIA and Continental Airlines engines, indicate that the meshing action of the CF6-50 engine's LPT rotor is being impeded. The turbine disk growth that was noted on the Continental Airlines engine shows that the limited meshing action allowed the overspeed of the LPT. Therefore, the Safety Board believes that the Federal Aviation Administration (FAA) should require GE to modify the CF6-50 engine to eliminate the impediments to the aft translation of the LPT rotor that limits the amount of meshing that occurs in the event of an FMS fracture.

¹¹ Meshing is the desired clashing of the turbine blades and vanes following a turbine rotor shaft fracture that is intended to decelerate the rotor and to break the blades into small particles, thus reducing the likelihood of blades penetrating an engine casing.

¹² A surge is a disruption of the airflow through the compressors resulting in a stagnation or reversal of the airflow and is typified by loud reports or bangs and flames from the inlet and tailpipe.

¹³ When a disk exceeds its rotational speed limit, the extreme centrifugal loads cause plastic deformation of the part so that the diametrical dimensions of the disk are greater following the overspeed event.

Because of other incidents, the Safety Board is also concerned about the LPT containment capability of GE's CF6-80 series engines. On January 24, 1996, American Airlines flight 1745, an Airbus Industrie A300-600 airplane, experienced an uncontained LPT failure in the No. 1 engine, a GE CF6-80C2A5, just after takeoff from Philadelphia, Pennsylvania. It was operating on an IFR flight plan under the provisions of 14 CFR Part 121 as a regularly scheduled passenger flight from Philadelphia to San Juan, Puerto Rico. The flightcrew reported that as the airplane was climbing through 1,000 feet, they heard a "soft thunk" and the No. 1 engine spooled down to idle. The airplane returned and landed at Philadelphia without further incident, and none of the passengers and crewmembers were injured. The flightcrew reported that the No. 1 engine ran at idle power until the crew shut it down after the airplane had landed.

Examination of the No. 1 engine revealed that the core cowl had a 15-inch long (circumferential) by 6-inch wide (axial) hole in the plane of the stage 4 LPT rotor. There were numerous dents and impact marks on the underside of the left wing's inboard aileron and the outboard side of the inboard flap track fairing, both of which are directly aft of the No. 1 engine's exhaust.¹⁴

The engine was disassembled and examined under the direction of the Safety Board at Motoren-und Turbinen-Union (MTU), Hannover, Germany.¹⁵ The disassembly revealed that the tip of one interturbine temperature ($T_{4.9}$)¹⁶ probe had broken off and impacted one stage 1 LPT blade, causing a fatigue fracture of the airfoil near the blade tip shroud (see figure 2). All of the stage 2, 3, 4, and 5 LPT blades were found in their respective disks; however, all were fractured transversely across the airfoils at various lengths above the blade root platforms. The disassembly also revealed that the LPT case had a 17-inch by 2-inch wide hole in the stage 4 LPT plane of rotation. The damage to the LPT rotor was progressively worse along the gaspath, suggesting that the stage 1 LPT blade tip separated first, that all of the blades in the following stages were then fractured, and that the mass of material became larger as it progressed through the rotor, subsequently resulting in a case rupture in the stage 4 area.

¹⁴ There was no indication that any of the material that exited through the core cowl struck the wing or fuselage.

¹⁵ American Airlines had the maintenance and repair of its GE CF6-80C2 engines contracted out to MTU at that time.

¹⁶ Gas turbine engine convention is to number the aerodynamic engine stations with station 1 being at the engine inlet and to use progressively higher numbers along the gas path to the exhaust nozzle. Generally, the number is accompanied by a prefix P (pressure) or T (temperature). In the CF6-80 series engine, station 4.9 would indicate that the probe was located between the high and low pressure turbine rotors.

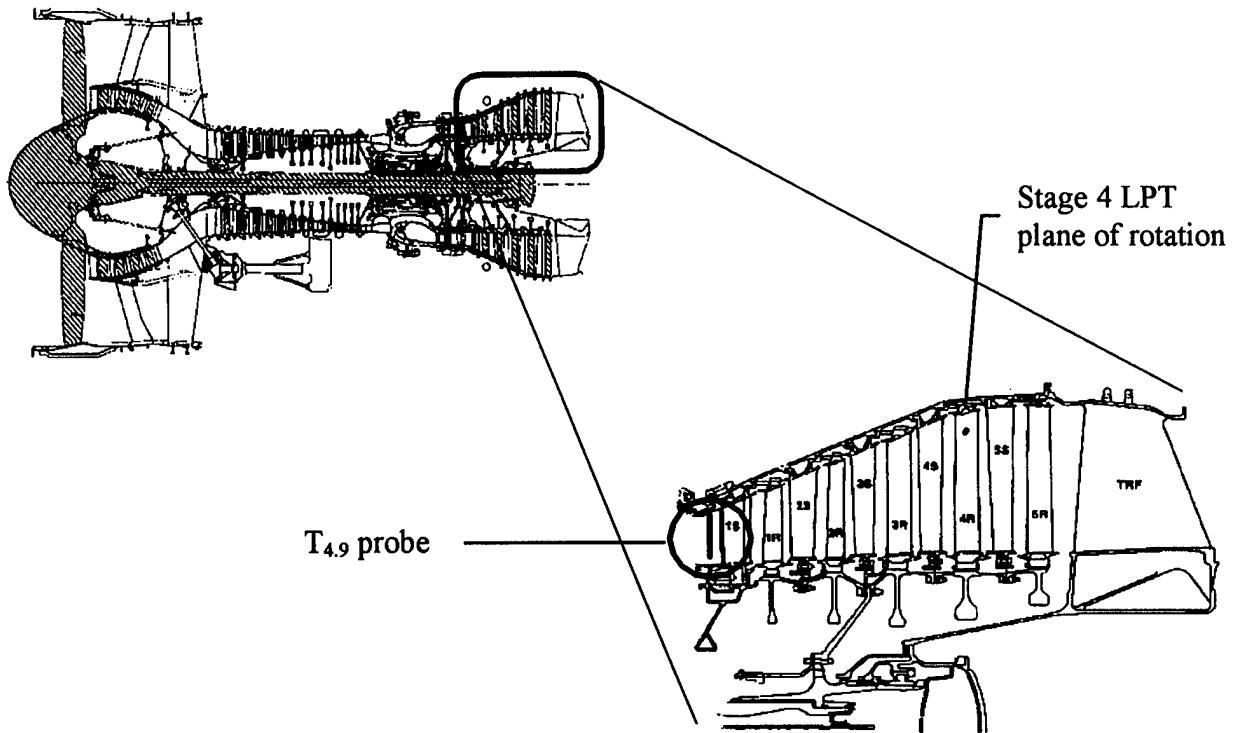


Figure 2. Cross section of CF6-80C2 engine and expanded view of LPT module

The Safety Board is aware of a similar event that occurred on September 5, 1997, when a Federal Express (FedEx) McDonnell Douglas MD-11 airplane, equipped with GE CF6-80C2 engines, had an uncontained LPT failure in the plane of the stage 4 LPT rotor. The disassembly of the FedEx engine showed that a stage 1 LPT airseal segment had broken loose from the LPT case and passed through the gaspath causing the breakage of the downstream turbine blades. As in the American Airlines LPT, the damage in the FedEx LPT rotor was more extensive downstream along the gaspath. The evidence shows that both the American Airlines and FedEx LPT cases withstood the initial containment challenge of the separation of an LPT blade; however, neither case could withstand the loads imparted by the resultant mass of broken LPT airfoils. This suggests that the design containment capability of the LPT case is inadequate.

To gain a clearer understanding of the number and frequency of uncontained LPT failures in CF6 engines, the Safety Board requested, and GE provided, a list of all such failures that have occurred in the CF6-50 and -80 series commercial engine fleet. The GE data show that the CF6-50 engine had experienced 25 uncontained LPT failures as of 1997, including the PIA and Continental Airlines FMS fracture events, and that the CF6-80C2 engine had experienced 6 uncontained LPT failures as of 1997, including the American Airlines and FedEx events. GE attributed these uncontained LPT failures to LPT blade fractures, FMS fractures, and other causes.

Turbine engine rotor cases are required to ensure containment of fractured blades by 14 CFR 33.19, which states in part that "the design of the compressor and turbine rotor cases must provide for the containment of damage from rotor blade failure." The requirements for

turbine containment are further addressed in 14 CFR 33.75, which notes in part that "any probable single or multiple failure...will not cause an engine to...burst (release hazardous fragments through the engine case)." Because the uncontained LPT failures in the CF6-50 and -80C2 engines were attributed to a number of different causes, the LPT containment capability of these engines must be improved to comply with 14 CFR 33.19 and 33.75.

The Safety Board notes that as a result of uncontained LPT failures that were initiated by blade or shaft fractures in the Pratt & Whitney (P&W) JT8D-1 through -17AR and JT9D engines, the FAA required modification of those engines to improve the LPT containment through Airworthiness Directives 97-19-14 and 96-25-10, respectively.¹⁷ The same standard should apply to GE CF6 engines. Therefore, the Safety Board believes that the FAA should require GE to improve the ability of the CF6-50 and the CF6-80 series engines to prevent fractured LPT blades from being liberated through the engine cowling.

Therefore, the National Transportation Safety Board recommends that the Federal Aviation Administration:

Require General Electric Aircraft Engines to modify the CF6-50 engine to eliminate the impediments to the aft translation of the low pressure turbine rotor that limits the amount of meshing that occurs in the event of a fan midshaft fracture. (A-98-125)

Require General Electric Aircraft Engines to improve the ability of the CF6-50 and the CF6-80 series engines to prevent fractured low pressure turbine blades from being liberated through the engine cowling. (A-98-126)

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in these recommendations.

By 
Jim Hall
Chairman

Enclosure

¹⁷ The CF6-50 series engine, which was first certificated in 1972 and has about 2,008 engines in service, experienced 25 uncontained LPT failures. The CF6-80 series engine, which was first certificated in 1981 and has about 2,977 engines in revenue service, experienced 6 uncontained LPT failures. In comparison, the JT8D-1 through -17AR engine series, which was first certificated in 1961 and has about 9,975 engines in service, experienced about 55 uncontained LPT failures. The JT9D engine, which was first certificated in 1968 and has about 566 engines in service, experienced 64 uncontained LPT failures. All of the uncontained LPT failures in the GE CF6-50 and -80 series engines and in the P&W JT8D and JT9D engines were blade penetrations caused by fractures of the LPT blades or the fracture of the LPT turbine drive shaft.

National Transportation Safety Board
Washington, D.C. 20594

Brief of Incident

Adopted 07/31/98

NYC961A036
FILE NO. 6000 12/06/95 JAMAICA, NY

	AIRCRAFT REG NO.	APBAK	TIME (LOCAL) - 21:50 EST
MAKE/MODEL	-Boeing-747-240		
ENGINE MAKE/MODEL	-G E CF6-50E2		
AIRCRAFT DAMAGE	-Minor		
NUMBER OF ENGINES	-4		
OPERATING CERTIFICATES	-NONE		
NAME OF CARRIER	-PAKISTAN INTERNATIONAL AIRLINE		
TYPE OF FLIGHT OPERATION	-Scheduled -International -Passenger/cargo		
REGULATION FLIGHT CONDUCTED UNDER	-14 CFR 129		

LAST DEPARTURE POINT DESTINATION	CONDITION OF LIGHT - Night (dark)
- Same as Incident - PARIS, FRANCE	
AIRPORT PROXIMITY	- Off airport/airstrip
AIRPORT NAME	- JOHN F KENNEDY INTL
RUNWAY IDENTIFICATION	- Unk/Nr
RUNWAY LENGTH/WIDTH (Feet)	- Unk/Nr
RUNWAY SURFACE	- Unk/Nr
RUNWAY SURFACE CONDITION	- Unk/Nr

WEATHER INFO SOURCE- Weather observation facility

BASIC WEATHER	- Visual (VMC)
LOWEST CEILING	- 2500 FT Overcast
VISIBILITY	- 20.000 SM
WIND DIR/SPEED	- 260 /007 KTS
TEMPERATURE (F)	- 39
OBSTR TO VISION	- None
PRECIPITATION	- None

PILOT-IN-COMMAND	AGE - 59	FLIGHT TIME (Hours)
CERTIFICATES/RATINGS		
Airline transport		TOTAL ALL AIRCRAFT - 15000
Multiengine land		LAST 90 DAYS - 50
INSTRUMENT RATINGS		TOTAL MAKE/MODEL - 4000
Airplane		TOTAL INSTRUMENT TIME - Unk/Nr

After takeoff, about 1,000 ft agl, the crew of the Boeing 747-240 heard a "thudding noise," followed by a loss of power in the number two engine. An engine shut down was completed, and an uneventful landing was made at the departure airport. The airplane was equipped with General Electric CF6-50E2 engines. Examination revealed that the low pressure turbine module, which included a portion of the fan mid shaft (FMS) and turbine rear frame, was missing. The airplane sustained damage to the left wing leading and tailing edge flaps, the left main wing landing gear doors, and the number one engine. Examination of the number two engine revealed a fracture face on the forward end of the FMS that showed multiple fatigue origins and circumferential cracks. There were also areas on the FMS that were heat affected. The FMS had previously been installed in a CF6-50 engine that had sustained a failure of the number 3 bearing inner race. The engine had been inspected by company personnel, and records did not reflect that they inspected the FMS for heat affected material. Fatigue cracks located in the heat-affected areas were found to have Sermetel paint and debris in the cracks.

Brief of Incident (Continued)

NYC961A036	FILE NO. 6000	12/06/95	JAMAICA, NY	AIRCRAFT REG NO. APBAK	TIME (LOCAL) - 21:50 EST
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Occurrence# 1 LOSS OF ENGINE POWER (TOTAL) - MECH FAILURE/MALF
Phase of operation TAKEOFF - INITIAL CLIMB

Findings

1. 1 ENGINE
2. TURBINE ASSEMBLY, SHAFT - FATIGUE
3. MAINTENANCE, INSPECTION OF AIRCRAFT - INADEQUATE - COMPANY MAINTENANCE PERSONNEL

The National Transportation Safety Board determines the probable cause(s) of this incident was:
failure of the number two engine fan mid shaft, due a fatigue fracture caused by a previous bearing failure, and
failure of the operator's maintenance personnel to detect the cracks during subsequent inspections.



National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: December 18, 1998

In reply refer to: A-98-127 through -128

Honorable Jane F. Garvey
Administrator
Federal Aviation Administration
Washington, D.C. 20591

On April 18, 1997, at 1824 Pacific daylight time, America West flight 66 (AWE66), a Boeing 737, and Ameriflight 1898 (AMF1898), a Beech 99, were involved in a near-midair collision approximately 25 miles south of McCarran International Airport, Las Vegas, Nevada. A flight attendant in the cabin fell and was seriously injured as AWE66 maneuvered to avoid the Ameriflight aircraft. Both flights were operating in visual meteorological conditions at the time of the accident.¹

AMF1898 had departed Las Vegas, en route to Burbank, California, as a nonscheduled, domestic cargo flight under 14 Code of Federal Regulations (CFR) Part 135. AWE66 had departed from John Wayne - Orange County Airport as a scheduled passenger flight operating under 14 CFR Part 121. The pilot of AMF1898 had elected to depart Las Vegas on a visual flight rules (VFR) flight plan and to fly at 10,500 feet. A review of the recorded voice communications between the radar controller at the Las Vegas terminal radar approach control (TRACON) and the crews of each airplane indicated that the controller terminated radar services with AMF1898 at the lateral limit of the Las Vegas class B² airspace. AWE66 contacted the Las Vegas radar controller about 40 seconds later, about 45 miles southwest of Boulder City at 12,000 feet. The flight was directed to descend to an altitude of 10,000 feet on heading 020. One minute later, the controller issued traffic to the crew of AWE66, "twelve o'clock three miles

¹ In accordance with 49 CFR Part 830.2, the Safety Board classified this event as an aircraft accident because of the serious injury to the flight attendant.

² Class B airspace is generally defined as that airspace from the surface to 10,000 feet mean sea level surrounding the nation's busiest airports in terms of airport operations or passenger enplanements. The configuration of each Class B airspace area is individually tailored and consists of a surface area and two or more layers (some Class B airspace areas resemble upside down wedding cakes). An air traffic control (ATC) clearance is required for all aircraft to operate in class B airspace, and all aircraft that are so cleared receive separation services within the airspace.

opposite direction, altitude indicates nine thousand three hundred," and then instructed the crew to "climb as you wish." Twenty seconds later, the controller advised AWE66 that the traffic was no longer a factor. The pilot replied, "That was close."

On initial contact with Las Vegas TRACON, the controller issued AWE66 a descent clearance and vector that placed it in direct conflict with AMF1898. The controller then issued a traffic advisory to AWE66 and authorized a climb, if necessary, to comply with an anticipated traffic alert and collision avoidance system (TCAS) resolution advisory (RA),³ recognizing that at least one of the two aircraft would need to maneuver to avoid the other. AMF1898 had been receiving radar advisories from the Las Vegas TRACON until less than 2 minutes before the accident. ATC services were terminated at the class B airspace boundary despite an earlier pilot request to continue VFR radar traffic advisory services for the duration of the flight.

After a departing VFR aircraft leaves charted class B airspace, controllers are no longer required to provide radar advisory service. Although fully within the scope of her authority under current rules, the controller's decision to terminate service to AMF1898 immediately after the aircraft exited class B airspace eliminated the possibility of providing either a traffic advisory to the pilot or a suggestion that AMF1898 remain at or below 9,500 feet until passing AWE66. Instead, AWE66 received a late advisory, AMF1898 received no ATC assistance at all, and an accident occurred.

This accident points out an anomaly in the level of service provided to VFR aircraft operating in terminal areas. Air traffic controllers are required to provide advisories to aircraft departing airports located within class B airspace areas only until the aircraft exits class B airspace, which could in some cases result in termination of radar service as soon as 5 to 7 miles after departure. The same aircraft departing an airport located in class C⁴ airspace, normally of lower traffic density and complexity than class B, would be entitled to radar advisory service until at least 20 miles after departure because controllers are prohibited from terminating radar service within the class C outer area without pilot request. It seems reasonable that aircraft operating near class B airspace, by definition the most complex terminal airspace in the United States, should receive at least the same level of service as aircraft operating near less complex class C airports. Extending the availability of mandatory advisory services to cover the most likely areas for encounters between VFR aircraft and those operating under IFR would improve

³ RAs are visual and aural warnings from TCAS that alert pilots to a nearby aircraft presenting a collision threat. RAs direct pilots to pitch the airplane nose-up or nose-down, as required, to resolve the collision threat.

⁴ Class C airspace is generally defined as that airspace from the surface to 4,000 feet above the airport elevation surrounding those airports that have an operational control tower, are serviced by a radar approach control, and have a certain number of instrument flight rules (IFR) operations or passenger enplanements. Although the configuration of each class C area is individually tailored, the airspace usually consists of a charted area of 5 nautical mile radius extending from the surface to 4,000 feet above airport elevation, a charted outer circle from 5 to 10 nautical miles radius extending from 1,200 feet to 4,000 feet above airport elevation, and an uncharted outer area generally including the remainder of the airport approach control's airspace to a minimum radius of 20 miles from the airport. Each person must establish and maintain two-way radio communications with the ATC facility providing air traffic services prior to entering the charted class C airspace. Class C services include separation of VFR aircraft from IFR aircraft.

safety by reducing the chance of conflicts, such as the one that precipitated this accident. The Safety Board believes that the Federal Aviation Administration (FAA) should revise Handbook 7110.65, "Air Traffic Control," to require that controllers provide pilots of aircraft departing class B terminal areas under VFR the option of continuing to receive radar advisory services until leaving airspace delegated to the applicable terminal radar approach control facility.

The design of the CRESO 3 standard terminal arrival⁵ (STAR) into Las Vegas appears to have contributed to this near-midair collision. Because of the surrounding high terrain, southbound VFR flights departing Las Vegas are concentrated in the location of this accident. The CRESO 3 STAR routing directs air carrier traffic into the same area, descending in a direction opposite to the departing VFR flights. Arrival procedures, such as the CRESO 3, are developed in accordance with FAA Order 7100.9B, "Standard Terminal Arrival (STAR)." This order does not address known concentrations of VFR traffic as a consideration in the selection of STAR routes, except possibly through the interpretation of a general direction that STARs be "compatible with local traffic flow management requirements." However, in light of the known limitations of visual traffic separation, the placement of VFR and IFR traffic flows in close proximity should be minimized in high density areas where conflicts are likely.

As the result of an inquiry from the Safety Board regarding this accident, on October 15, 1997, the manager of the Las Vegas TRACON stated:

In response to the request for information regarding planned airspace changes that would alleviate the possibility of another incident involving a VFR aircraft climbing in the path of an IFR aircraft on the CRESO arrival, such as the aircraft accident involving AWE66, the changes involved encompass a long-term project, require much more planning and development, and have yet to be instituted.

As of July 1998, the CRESO arrival remains unchanged. The Safety Board would welcome further information on the FAA's progress on the modification of airspace and procedures in the Las Vegas area. The Safety Board believes that the FAA should revise Order 7100.9, "Standard Terminal Arrival (STAR)," to provide a specific instruction to STAR designers to segregate concentrated IFR traffic from concentrated VFR traffic unless no reasonable alternative is available. Further, existing procedures, including the CRESO 3 STAR, should be reviewed to ensure compliance with this requirement and revised if necessary.

Therefore, the National Transportation Safety Board recommends that the Federal Aviation Administration:

Revise Handbook 7110.65, "Air Traffic Control," to require that controllers provide pilots of aircraft departing class B terminal areas under visual flight rules the option of continuing to receive radar advisory services until leaving airspace delegated to the applicable terminal radar approach control facility. (A-98-127)

⁵ A planned air traffic control IFR arrival procedure published for pilot use in graphic and/or textual form. STARs provide transition from the en route structure to an outer fix or an instrument approach fix/arrival waypoint in the terminal area.

Revise Order 7100.9, "Standard Terminal Arrival (STAR)," to provide a specific instruction to STAR designers to segregate concentrated instrument flight rules traffic from concentrated visual flight rules traffic unless no reasonable alternative is available. Further, existing procedures should be reviewed to ensure compliance with this requirement and revised if necessary. (A-98-128)

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in these recommendations.

By: 
Jim Hall
Chairman



National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: January 14, 1999*

In reply refer to: A-99-1 and -2

Honorable Jane Garvey
Administrator
Federal Aviation Administration
Washington, D.C. 20591

On September 6, 1997, at 6:35 p.m. local time, a North American T-6-SNJ5, N1047C, experienced a loss of control in flight while maneuvering near Woodward Field, Camden, South Carolina.¹ The airplane was operated by the Western North Carolina Air Museum under the provisions of Title 14 Code of Federal Regulations Part 91 and visual flight rules. Visual meteorological conditions prevailed at the time of the accident. The personal flight had originated at 6:20 p.m. from Woodward Field; the commercial pilot had not filed a flight plan. The pilot and his passenger were fatally injured, and the airplane was destroyed.

A friend of the pilot stated that the pilot was on the last flight of the day after giving rides in the airplane all day at an airshow. The pilot was taking the passenger for a ride to thank the passenger for his help throughout the day. According to the pilot's friend, the fuel tank had been refilled before a previous flight, and he estimated that the airplane had between 80 and 85 gallons of fuel on board.

Two witnesses in the area observed a low-flying airplane that was doing aerobatics, that is, steep turns, about 60° to 70° of bank. They heard the airplane engine "begin missing." The engine quit 10 seconds later. During this 10 seconds, the pilot remained in a left bank. According to the witnesses, after the airspeed deteriorated, the aircraft entered a right-hand spin.

* This is a revised version of the recommendation letter issued on January 14, 1999. The original letter has been revised to correct errors in references to accidents involving aerobatics.

¹ NTSB accident No. ATL97FA134.

According to Advisory Circular (AC) 91-48, "Acrobatics—Precision Flying With a Purpose," the Federal Aviation Administration (FAA) currently does not "require the performance of 'pure' acrobatics maneuvers during the flight test other than the spin requirement for airplane flight instructor applicants. Therefore, the FAA has not been involved in establishing criteria for the performance of acrobatic maneuvers . . ." Federal Aviation Regulation (FAR) 91.303 defines acrobatic flight as "an intentional maneuver involving an abrupt change in an aircraft's attitude, an abnormal attitude, or abnormal acceleration, not necessary for normal flight." In AC 91-48, under discussion of the definition of acrobatic flight, the FAA notes the requirement that occupants wear parachutes for maneuvers exceeding a bank of 60° relative to the horizon or a nose-up or nose-down attitude of 30° relative to the horizon.

Regarding the medical condition of the pilot-in-command of the aircraft that crashed near Woodward Field, the pilot's medical records indicated severe coronary artery disease for which he was receiving medical treatment with diltiazem. The autopsy report noted the same disease, and scarring of his heart noted on the autopsy report further indicated that he had probably had a myocardial infarction (heart attack) at some time long before his accident. The FAA was aware of the pilot's condition, required that he receive special evaluation for it, and granted him an Authorization for Special Issuance of a third class medical certificate, but the FAA did not restrict his certificate in any way (other than a requirement for near vision correction).

The FAA's Civil Aeromedical Institute (CAMI) in Oklahoma City, Oklahoma, completed a toxicological examination of specimens from the pilot on December 18, 1997. According to the report, the pilot tested positive for fluoxetine, norfluoxetine, cimetidine, and diltiazem. According to the 1998 *Physicians Desk Reference*, fluoxetine is a prescription antidepressant that can induce anxiety, drowsiness, nervousness, insomnia, and dizziness. The FAA does not permit an aviation medical examiner to issue a medical certificate to a pilot on mood-altering medications. Norfluoxetine is a metabolite of fluoxetine. Cimetidine (trade name Tagamet) is an antacid medication available over the counter. Diltiazem (trade name Cardizem) is a prescription medication often prescribed for patients with angina (chest pain due to blocked arteries in the heart). Possible side effects include low blood pressure and slowed heart rate, both of which would tend to reduce resistance to G-induced loss-of-consciousness (G-LOC). Cimetidine is known to significantly increase the blood levels of diltiazem when both medications are taken.

It is possible that the pilot's blood level of diltiazem increased as a result of the concomitant use of cimetidine, and that a relatively high-bank turn then resulted in enough acceleration (G-loading) to induce G-LOC and thereby incapacitate the pilot. The situation was greatly aggravated by the pilot's severe coronary artery disease, possibly resulting in incapacitation due to a sudden cardiac event.

The Safety Board has investigated two other accidents in which pilots with cardiac problems were fatally injured after performing aerobatics. On June 15, 1976, a pilot practicing aerobatic maneuvers in Goldsby, Oklahoma, entered an uncontrolled descent and crashed. The Board determined the probable cause of the accident to be the pilot's incapacitation due to a preexisting heart condition, which made him more susceptible to the G-forces of aerobatic

maneuvers.² On June 26, 1993, a pilot was performing aerobatics at an airshow in Concord, New Hampshire, when he entered a maneuver that, according to other aerobatic pilots, was unfamiliar to them. The Safety Board determined the probable cause of the accident to be the "loss of airplane control as the result of incapacitation."³ An autopsy revealed that the pilot had "severe atherosclerosis" and "an old . . . myocardial infarction scar." The only limitation on the pilot's medical certificate, however, was a requirement that the pilot use corrective lenses during flight.

On May 7, 1980, a pilot crashed near Olathe, Kansas, while practicing aerobic maneuvers in a Pitts Special S2S.⁴ As a result of its investigation of the accident, the Safety Board recommended that the FAA issue an advisory circular detailing the physiological effects of G forces (Safety Recommendation A-81-48). In response, the FAA issued AC 91-61, "A Hazard in Aerobatics: Effects of G-Forces on Pilots." According to the AC, the most important biomedical factor in aerobatic flight is the pilot's response to acceleration (G-loading). The AC also states that G-tolerance depends on an individual's height, age, elasticity of blood vessels, training, the responses of the heart and blood vessels, and general health. Further, "a well tuned cardiovascular system seems to recover more rapidly from many different kinds of stress" and "low blood pressure . . . lower(s) G-tolerance."

Thousands of pilots receive special issuance certificates for heart-related problems each year. As an illustration of the numbers involved, three of the heart-related categories are for high blood pressure (which normally does not require special issuance), coronary bypass surgery, and myocardial infarction (heart attack). According to the Records and Correspondence Section of the FAA Aeromedical Certification Division, as of December 31, 1997, there were 28,981 medical certificates issued to pilots with high blood pressure that were being treated by medications: 3,339 first-class medical certificates; 6,155 second-class medical certificates; and 19,487 third-class medical certificates. Of the medical certificates issued to pilots who had undergone coronary bypass surgery, 164 were first class; 227 were second class; and 2,305 were third class. Of the medical certificates issued to pilots who had experienced a heart attack, 203 were first class; 214 were second class; and 2,099 were third class.

The condition of the heart and blood vessels is an important factor in a pilot's tolerance of aerobatic flight. Such flight increases the risk of G-LOC for pilots with a heart condition or who take medication that results in low blood pressure or low heart rate. Further, aerobatic flight also endangers the passengers of these pilots and the spectators at airshows, where aerobatic maneuvers are often performed, should the pilot experience G-LOC. The safety of these pilots, their passengers, and the spectators at airshows would be greatly increased by ensuring that the pilots who perform aerobatics can tolerate the unique physiological stresses such maneuvers put on their bodies.

² NTSB accident file 3-3293.

³ NTSB Brief of Accident NYC93FA127.

⁴ NTSB Brief of Accident MKC80FA034.

FAR 67.401(d)(3) states that the Federal Air Surgeon may place on any special issuance medical certificate "any operational limitation needed for safety." Aviation Medical Examiners routinely enter limitations on medical certificates for pilots who require corrective lenses to meet applicable standards for visual acuity or who do not meet the color vision standard. The Safety Board believes that all pilots with special issuance certificates due to cardiac conditions that could affect their G-tolerance and all pilots taking medication that reduces G-tolerance should be restricted from engaging in aerobatic flight.

Therefore, the National Transportation Safety Board recommends that the Federal Aviation Administration:

Restrict all pilots with special issuance certificates due to cardiac conditions that could affect their G-tolerance from engaging in aerobatic flight. (A-99-1)

Restrict all pilots taking medication that reduces G-tolerance from engaging in aerobatic flight. (A-99-2)

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in these recommendations.



By: Jim Hall
Chairman



National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: January 11, 1999

In reply refer to: A-99-3

Honorable Jane F. Garvey
Administrator
Federal Aviation Administration
Washington, D.C. 20591

On September 2, 1998, at 2018 eastern daylight time, Swissair flight 111,¹ a McDonnell Douglas MD-11 registered as HB-IWF, departed from John F. Kennedy International Airport in Jamaica, New York. Swissair flight 111 was a regularly scheduled passenger flight from New York to Geneva, Switzerland, operating under the provisions of 14 Code of Federal Regulations Part 129.

About 56 minutes after departure while at flight level 330, the flightcrew declared "PAN PAN PAN"² and advised air traffic control (ATC) of smoke in the cockpit. The flightcrew requested to divert to a convenient airport and was cleared direct to Halifax International Airport in Nova Scotia, Canada. About 11 minutes after the report of smoke, the airplane's electrical systems began to deteriorate. The flightcrew then declared an emergency, and communications between ATC and the flightcrew ceased shortly thereafter. Approximately 6 minutes later, at 2231 Atlantic daylight time,³ the airplane crashed into the Atlantic Ocean near Peggy's Cove, Nova Scotia, Canada. All 14 crewmembers and 215 passengers were killed, and the airplane was destroyed. The Transportation Safety Board of Canada (TSB) is in charge of the accident investigation, and the National Transportation Safety Board is participating in accordance with the provisions of Annex 13 to the Convention on International Civil Aviation.

Approximately 85 percent of the airplane's wreckage has been recovered to date. Examination of the wreckage revealed evidence of considerable heat damage to ceiling areas both forward and aft of the cockpit bulkhead. This damage is consistent with the effects of a fire. Numerous sections of wiring from the cockpit overhead area also exhibited heat damage and burned insulation, and several of the

¹ The flight was also operating as Delta Air Lines flight 111 under a code-sharing agreement.

² According to the Federal Aviation Administration's (FAA) Aeronautical Information Manual, the signal "PAN-PAN" is used for an urgency condition.

³ The Atlantic time zone is 1 hour ahead of the eastern time zone.

wires from those sections showed evidence consistent with electrical arcing. Although some of the wires exhibiting arcing characteristics are from the entertainment system that is unique to the Swissair MD-11 fleet, others have been identified as original MD-11 wires.

On December 22, 1998, the TSB issued Aviation Safety Advisory 980031-1 to the Safety Board as the representative of the MD-11's State of Manufacturer; a copy of the advisory was also sent to Switzerland's Aircraft Accident Investigation Bureau, Transport Canada, and the FAA. The advisory points out that TSB investigators recovered two MD-11 electrical bus feed wires that show signs of arcing. The two wires are identified as the left emergency alternating current bus feed wire (wire number B205-1-10) and the left emergency direct current bus feed wire (wire number B205-4-6). If the wires were in place, the area of apparent arcing damage would be located approximately 2 inches aft of the right cutout in the "tub" that encloses the overhead circuit breaker panel.⁴ According to the advisory, the potential safety ramifications appear to be confined only to the MD-11 fleet.

TSB investigators also recovered the overhead circuit breaker panel and the upper avionics circuit breaker panel. Portions of each panel show evidence of substantial heat damage. The avionics circuit breaker panel is located along the right side of the cockpit behind the first officer's seat, but the upper portion of that panel extends into the area near the overhead circuit breaker panel.

In addition, TSB investigators participated in examinations of several other MD-11 airplanes that concentrated on the area from the cockpit to station 600 (near the forward doors of the airplane). The examinations showed the following:

- chafed, cracked, broken, and cut electrical and bonding wires in several areas, including the overhead and avionics circuit breaker panels and the forward drop ceiling area above the left (L) 1 and right (R) 1 doors and
- inconsistencies in the routing of wires and wire bundles, loose terminal connections, excessively small bend radii, unsealed electrical conduits, and open smoke barriers between the cockpit and cabin areas.

On December 10, 1998, the FAA issued Airworthiness Directive 98-25-11, "McDonnell Douglas MD-11 Series Airplanes," requiring a one-time inspection above the L1 and R1 doors to address the wire chafing issue discovered as part of the accident investigation. Also in December 1998, Boeing issued two MD-11 Alert Service Bulletins—MD-24A068 Revision 1 and MD-25A194 Revision 4—which address the specific discrepancies regarding the door areas. Further, SR Technics, on behalf of Swissair and along with Boeing, has voluntarily developed an engineering order that defines a comprehensive inspection of the wiring in the forward areas of the Swissair MD-11 airplanes. The Safety Board understands that the inspections completed to date have not uncovered any discrepancies that warrant regulatory action.

Although the apparent electrical arcing on Swissair flight 111 has not been determined to be a source of a fire, and Swissair's voluntary inspections of its MD-11 airplanes have not uncovered

⁴ The overhead circuit breaker panel is located in the cockpit ceiling between and behind the pilot seats. The tub is a fiberglass enclosure that forms a cavity for the overhead circuit breakers and associated wiring. The wiring is routed through oval cutouts located in the left and right aft portions of the tub.

serious discrepancies, the Safety Board is concerned about the recent discoveries of apparent electrical arcing damage to wiring near the accident airplane's overhead and avionics circuit breaker panels, the heat damage to those panels, and the wiring anomalies discovered in TSB's examination of MD-11 airplanes.

Therefore, the National Transportation Safety Board recommends that the Federal Aviation Administration:

Require, on an expedited basis, an inspection of all MD-11 airplanes for discrepancies of wiring in and around the cockpit overhead circuit breaker panel (including the area just aft of the tub enclosure) and the avionics circuit breaker panel. The inspection should include examinations for loose wire connections, inconsistent wire routings, broken bonding wires, small wire bend radii, and chafed and cracked wire insulation. (A-99-3)

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in this recommendation.

A handwritten signature in black ink, appearing to read "Jim Hall".

By: Jim Hall
Chairman



National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: January 19, 1999

In reply refer to: A-99-4

Honorable Jane F. Garvey
Administrator
Federal Aviation Administration
Washington, D.C. 20591

On August 31, 1998, the right main landing gear (MLG) of a Boeing 727-200 airplane, operated by DHL Worldwide Express, collapsed after an emergency landing at John F. Kennedy International Airport in Jamaica, New York. The emergency was declared after an unrelated No. 2 engine failure. The flight was an intended scheduled Title 14 Code of Federal Regulation Part 121 cargo flight from New York to Cincinnati, Ohio. None of the three flightcrew members or the two jumpseat passengers were injured, and the airplane sustained substantial damage as a result of the accident.

The right MLG was original equipment that had accumulated 44,554 flight cycles and 50,861 flight hours in 28 years and 6 months of service. Postaccident examination of the airplane by the National Transportation Safety Board revealed that the right MLG forward trunnion bearing support fitting lug had fractured and that postfracture loads on the fitting had spread the fracture faces apart by bending the outboard side of the lug.

The right MLG of the B-727 is a conventional, two-wheel landing gear with three support points: the forward trunnion, the aft trunnion, and the side strut (see figure 1). A trunnion link is mounted between the shock strut and the rear spar. The aft end of the trunnion link is pinned to the shock strut, and the forward end pivots in a spherical bearing mounted in the forward trunnion bearing support fitting.¹ The spherical bearing has external splines that are used for locking the bearing assembly and retaining it within the support fitting lug. The splines contact a portion of the inner surface of the lug, leaving the gaps between the splines exposed to possible corrosion. The trunnion bearing support fitting is a round housing made from 4330M steel. The inner bore of the housing has chrome electroplating, which is the bore's primary means for corrosion protection. The fitting is mounted on the rear spar of the wing with high-strength bolts.

¹ The design and location of the forward trunnion bearing support fitting are similar for all B-727 series airplanes.

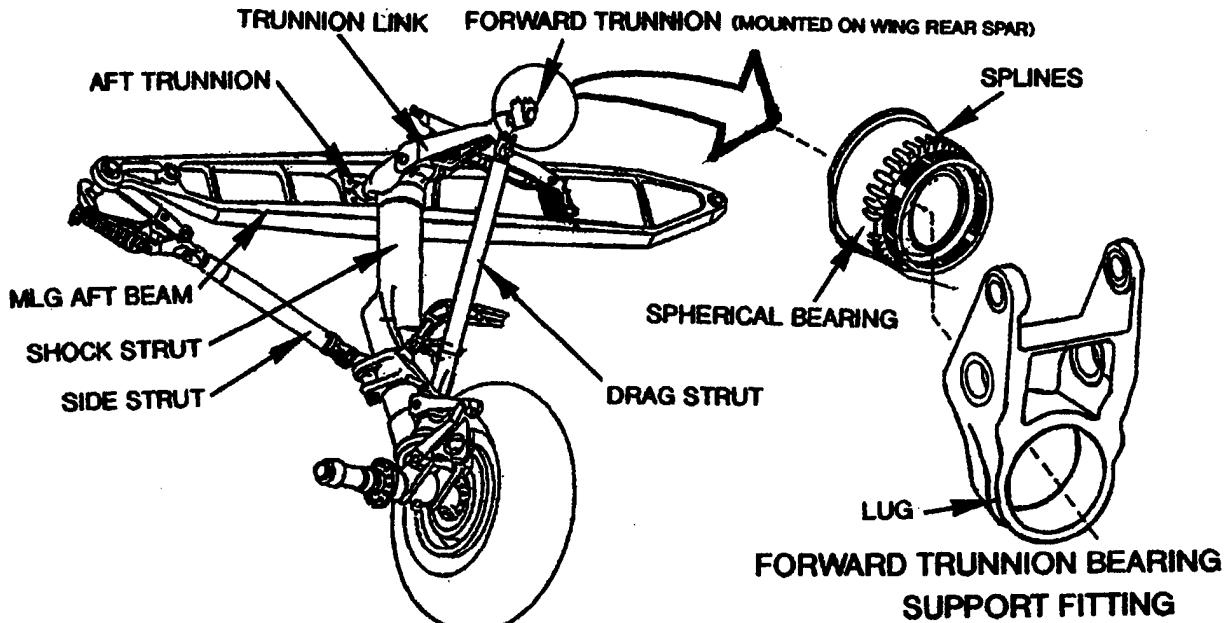


Figure 1. Boeing 727 Main Landing Gear Assembly

Examination of the trunnion bearing support fitting at the Safety Board's materials laboratory revealed corrosion at the forward edge of the fitting's lug in many of the exposed areas between the bearing splines. Fatigue cracking emanated from two locations within a severely corroded area, and intergranular stress corrosion cracking (SCC) stemmed from the fatigue cracking. This corroded area was 0.15-inch wide by 0.37-inch long by 0.07-inch deep. The fracture was caused by a combination of fatigue cracking and SCC.

According to Boeing's records, three other B-727 series airplane events involving the failure of a MLG forward trunnion bearing support fitting have occurred. The first of these failures, which involved a B-727 owned by Air Portugal, occurred in Frankfurt, Germany, in July 1988. Heavy corrosion was found at the forward edge of the forward trunnion bearing support fitting lug and bore, and the fracture was caused by intergranular SCC. The other two failures, which involved B-727s owned by Delta Air Lines, occurred in Denver, Colorado, in May 1989 and Albuquerque, New Mexico, in July 1997. The Safety Board investigated both of these cases and found that heavy surface corrosion on the forward trunnion bearing support fitting lug had caused either multiple fatigue regions or SCC.

On March 8, 1990, Boeing issued Service Bulletin (SB) 727-57-0179 (revised on June 13, 1991, and April 30, 1992), recommending (1) ultrasonic inspection of the forward trunnion bearing support fitting for SCC at least every 6 months or 1,500 flight cycles, whichever occurs first, and (2) magnetic particle inspection at 12,000 cycle intervals. The SB states that the inspections should continue until the fitting is replaced or the specified preventive modification of

the fitting is performed.² The preventive modification includes removing the fitting from the airplane, performing magnetic particle inspection, cleaning, and installing a moisture barrier Boeing Material Specification 5-95 sealant. The recommended actions of the SB are not currently mandated by a Federal Aviation Administration (FAA) airworthiness directive. As a result, some operators have developed their own visual and ultrasonic inspections that are performed at intervals up to every 30 months, but other operators do not perform the inspection at all. DHL did not inspect the fitting from the accident airplane.

The Safety Board is concerned that additional B-727 forward trunnion bearing support fittings may fail because of corrosion, fatigue, and SCC, which could jeopardize safety. The Safety Board is also concerned that no requirement exists for recurrent inspection and protection of the fitting with a moisture barrier. Periodic ultrasonic inspection is necessary to detect corrosion, cracks, and SCC in the trunnion fitting so that the part can be repaired or replaced or have the preventive modification performed. Also, the application of a proper moisture barrier is important to minimize the possibility of corrosion on new or existing fittings. Therefore, the Safety Board believes the FAA should require operators of all B-727 series airplanes to (1) conduct periodic ultrasonic inspections of the MLG forward trunnion bearing support fittings for corrosion, cracks, and SCC; (2) repair or replace these fittings if they are cracked or corroded; and (3) ensure that a proper moisture barrier is applied on new or existing MLG forward trunnion bearing support fittings to minimize corrosion.

Therefore, the National Transportation Safety Board recommends that the Federal Aviation Administration:

Require operators of all Boeing 727 series airplanes to (1) conduct periodic ultrasonic inspections of the main landing gear (MLG) forward trunnion bearing support fittings for corrosion, cracks, and stress corrosion cracking; (2) repair or replace these fittings if they are cracked or corroded; and (3) ensure that a proper moisture barrier is applied on new or existing MLG forward trunnion bearing support fittings to minimize corrosion. (A-99-4)

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in this recommendation.

By: 
Jim Hall
Chairman

² If cracked or corroded fittings are repaired, the SB states that the inspections may need to continue depending on the type of repair performed.



National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: February 3, 1999

In reply refer to: A-99-5 through -7

Honorable Jane F. Garvey
Administrator
Federal Aviation Administration
Washington, D.C. 20591

On October 12, 1997, about 1728 Pacific daylight time, an experimental category, amateur-built Adrian Davis¹ Long-EZ airplane, N555JD, crashed into the Pacific Ocean near Pacific Grove, California. Air traffic control communications indicated that the airplane had departed from the Monterey Peninsula Airport's runway 28L about 1712, and the pilot performed three touch-and-go landings and departed to the west moments before the accident. Witnesses reported that they heard engine popping and a reduction in engine noise before the accident. The pilot made no distress calls. The pilot was killed, and the airplane was destroyed.

An airport maintenance technician helped the pilot push the airplane out of the hangar before the accident flight and was present during the preflight check. The technician said he told the pilot that less than a quarter tank of fuel was available in the left tank and less than half a tank of fuel was available in the right tank. The technician estimated the fuel quantity based on the assumption that the presentations on the unmarked sight gauges were linear. However, Long-EZ fuel tank sight gauges are not linear, and examination of other Long-EZ sight gauges revealed that the actual fuel on-board the airplane would have been much lower than the technician's estimate. The fuel tank sight gauges were not visible from the front cockpit. The technician loaned the pilot a shop inspection mirror so it would be possible for the pilot to see the fuel tank sight gauges in flight. The pilot told the technician that he did not wish to refuel the airplane.

The technician said he heard the engine start and run for a short time and quit. Watching from the hangar, he saw the pilot turn in the front cockpit toward the fuel selector handle behind his left shoulder. Shortly afterward, the technician heard the engine restarted. The pilot signaled an "okay" to the technician and taxied toward the runway. After the airplane departed the traffic pattern to the west, witnesses reported that the airplane climbed to 350 to 500 feet and was in

¹ The Federal Aviation Administration (FAA) issues experimental airworthiness certificates for amateur-built aircraft with the original builder's name as the manufacturer. Any subsequent owner may change the registration number but not the Certificate of Airworthiness. Hence, the builder's name appears on the Certificate of Airworthiness.

level flight when, after the reduction in engine noise, it pitched slightly nose-up, entered a steep right bank, and descended nose-first into the ocean.

Safety Board investigators determined that the weight and center of gravity of the accident airplane were within the original planned limits for the Long-EZ and would not have affected the flight or stall characteristics of the airplane. Based on the airplane's fueling history, the technician's observations of the fuel levels at engine start, and the normal fuel consumption rates of the airplane's Lycoming O-320-E3D engine, the airplane would have had about 3 1/2 gallons of fuel available from the left tank and about 6 1/2 gallons of fuel available from the right tank. The Safety Board found that witness statements were consistent with the checkout pilot's description of postflight engine shut-down² and concluded that the engine lost power because of fuel starvation or exhaustion.³

The Long-EZ was designed by Rutan Aircraft Factory and amateur-built from the Rutan plans as a single-engine, tandem cockpit, swept-wing, canard-equipped⁴ airplane with laminar flow airfoils.⁵ The engine is mounted aft of the cabin, and both cockpits have pitch and roll side-stick controls.

The all-composite⁶ airplane has a canard with elevators for pitch control. The swept wings have taper and twist and have winglets installed at the tips. According to technicians from the Experimental Aircraft Association (EAA), the rudder system used in the Long-EZ is very sensitive⁷ in low-speed flight. According to the former Rutan chief engineer, the airplane has a substantial glide ratio due to its aerodynamically clean design but will pitch up and roll right when the airspeed is slow and the right rudder is depressed. When the airspeed is higher, he stated that roll rates are much higher and that it is possible to aileron-roll the airplane from rudder application only (ailerons neutral).

According to the Long-EZ owner's manual, the airplane has good flight characteristics at minimum speed. The manual describes "stalls" as maneuvers that result in increased aft stick force or mild pitch or roll oscillations. Spin attempts result in a spiral that reportedly can be recovered by neutralizing rudder and pulling out normally. The Long-EZ design incorporates many high performance features but would not be considered "high performance" by Federal

² The checkout pilot told Safety Board investigators that when the engine was stopped by closing the mixture (shutting off the fuel supply) at the end of a flight, loud popping normally occurred.

³ For more information, see Brief of Accident #LAX98FA008 (enclosed).

⁴ A canard is a lifting airfoil located in the front portion of an airplane that eliminates the need for a tail-mounted horizontal stabilizer.

⁵ Laminar flow airfoils are used in high performance, complex aircraft such as the Beech Starship. The airfoil construction minimizes drag but is sensitive to boundary layer separation (stall).

⁶ The Long-EZ airplane is constructed of shaped foam and fiberglass/epoxy materials.

⁷ The rudder system in the Long-EZ comprises two independent, outward acting rudders on the rear of the winglets. Activation in low speed flight is very easy; however, the owners manual cautions against inadvertent use because a substantial yaw will result.

Aviation Administration (FAA) definition⁸ because the airplane has no flaps or controllable pitch propeller. Nonetheless, its laminar flow airfoils have greater lift-to-drag ratios than most general aviation airplanes. Because the airplane has no flaps, its landing speeds are greater than many small airplanes, and it has a wings level, power off stall speed of about 71 mph.⁹

The Long-EZ airplane has two 26-gallon fuel tanks, one at each wing root. Fuel quantity is determined by viewing the rear cockpit sight gauges. N555JD was also equipped with a fuel totalizer.¹⁰ Fuel is selected from the left or the right tank by turning a fuel selector handle. According to the Rutan design, the fuel selector handle is to be located just aft of the nose wheel position window between the pilot's legs and is oriented toward the right to select the right tank, left to select the left tank, and another quarter turn to the left to select the "Off" position. A placard associated with the Rutan design clearly identifies the fuel selector handle positions.

The amateur builder of N555JD modified the fuel system design by locating the fuel selector handle on the left side of the bulkhead that forms the front cockpit seat back. It was positioned approximately behind the front-seat pilot's left shoulder (see figure 1). The builder also changed the orientation of the handle so that upward selected "Off," right selected the left tank, and downward selected the right tank. The corresponding 3-position fuel selector valve was installed inside the rear cockpit on the front of the engine firewall just behind the rear seat and was connected to the selector handle via two torque tubes and a universal joint. The selector handle was about 4 feet forward of the fuel selector valve. No placard or marking existed (nor was it required) on the fuel selector handle base that would have indicated to the pilot its operating position. Further, as has been stated, the sight gauges were not marked to quantify the amount of fuel in the tanks.

⁸ The FAA defines "high performance" as an airplane that has an engine with greater than 200 horsepower or that has retractable landing gear, flaps, and a controllable pitch propeller (14 Code of Federal Regulations (CFR) Part 61.31 (e)).

⁹ The maximum stall speed allowed for aircraft certificated under 14 CFR Part 23 is 61 knots (70 mph).

¹⁰ Although the accident airplane was equipped with sight gauges, which were part of the original design, it also had a fuel totalizer installed in the front instrument panel that required pilot entry of the starting fuel amount. Witness statements provide no evidence that the totalizer was used, and the checkout pilot stated he was not familiar with it and did not provide any instruction on its use.

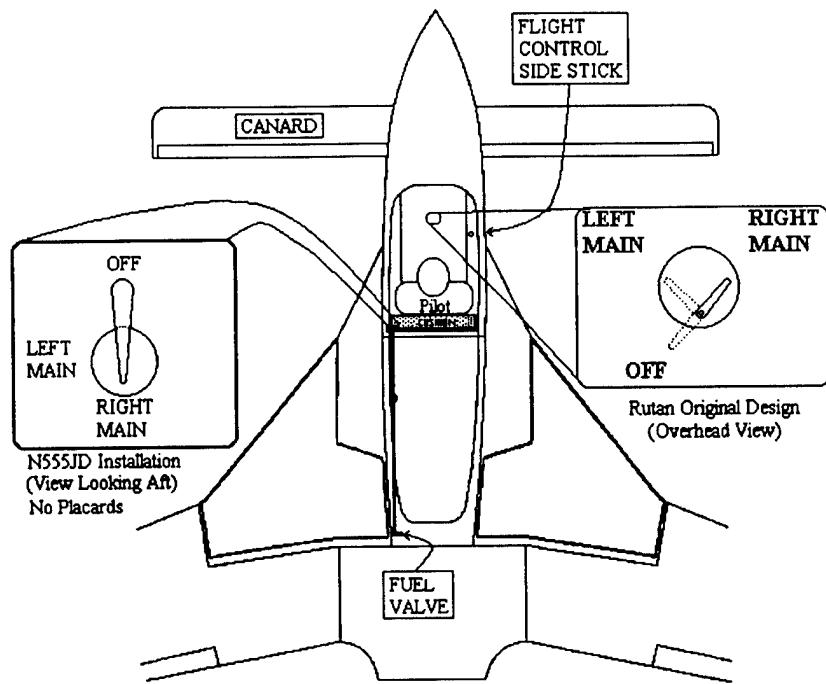


Figure 1—Comparison of fuel selector handle locations in Long-EZ

N555JD vs. Original design

The flight control side sticks in both cockpits were installed in armrests on the right side of the cockpits, measured about 6 inches high, and were similar in function to a conventional control stick. During the postaccident investigation, simulation by Safety Board staff showed that the front-seat pilot in the accident airplane would have had to loosen his shoulder harness, completely release the flight control stick, turn in his seat, and stretch to his left when reaching over the left shoulder with his right hand to change the position of the fuel selector handle on the accident Long-EZ airplane. The Safety Board investigator, in every simulation, inadvertently applied right rudder when turning his body and reaching for the fuel selector handle. This finding concerned the Safety Board because the design change that moved the fuel selector handle introduced a safety hazard in N555JD. On the basis of the accident circumstances and witness accounts, the Board concluded that the accident pilot probably inadvertently applied right rudder while manipulating the fuel selector, precipitating the loss of control that preceded the accident.

The fuel selector valve assembly from the accident airplane was found in an intermediate position; the selector valve port from the right tank fuel supply line was about 33 percent open to the engine feed line and the left was about 2 to 4 percent open to the engine feed line. An engine test run in a test cell showed that full power could be attained (with fuel in both tanks) with the selector valve in the "as found" position. However, with fuel in only one tank and the other fuel

line open to the atmosphere to simulate an empty tank, the engine lost power with the fuel selector valve in the "as found" position. The position of the fuel selector handle from the accident airplane could not be determined because of damage to the torque tubes between the valve and the selector handle.

Postaccident examination of the engine revealed no mechanical failures, and internal continuity of the drive train components was established. The magneto¹¹ was tested and produced a normal spark. The fuel lines had no leaks or blockages. The evidence indicated that the engine was capable of producing normal power if sufficient fuel was supplied to it.

The Safety Board determined that the probable cause of the accident was the pilot's diversion of attention from the operation of the airplane and his inadvertent application of right rudder that resulted in the loss of airplane control while attempting to manipulate the fuel selector handle. Also, the Board determined that the pilot's inadequate preflight planning and preparation, specifically his failure to refuel the airplane, was causal. The Board determined that the builder's decision to locate the unmarked fuel selector handle in a hard-to-access position, unmarked fuel quantity sight gauges, inadequate transition training by the pilot, and his lack of total experience in the type of airplane were factors in the accident.

N555JD had a special airworthiness certificate in the experimental category¹² that was issued on May 5, 1987. The airplane had been flown about 850 hours and had been sold two times since its construction. Because N555JD was an experimental, amateur-built airplane, specific deviations from the original plans did not require FAA approval nor was a placard required to identify fuel selector valve positions or to indicate that there had been a change in the airplane's design. However, the overall design is evaluated for safety and airworthiness by the FAA prior to issuing the experimental airworthiness certificate.

The Safety Board is concerned that the pilot of N555JD, who had minimal¹³ pilot-in-command experience in the accident airplane, may not have been adequately familiar with the operating positions of the unmarked fuel selector handle. This is of special concern because in its modified location and orientation, the fuel selector handle's operating positions would have been less intuitively obvious than if it had been installed as originally designed. Also, demonstrations indicated that the fuel selector handle was out of the accident pilot's view and in an awkward position that a pilot of similar height as the accident pilot (5' 10") could not operate without releasing the flight control stick. An interview with the checkout pilot revealed that he

¹¹ This engine had one magneto and one electronic ignition installed. The spark plugs showed evidence of normal ignition, and the magneto functioned normally when its impulse-coupling was rotated by hand. The electronic ignition was not tested.

¹² Title 14 CFR 21.191 "Experimental Certificates," allows experimental airworthiness certificates to be issued for, among other purposes, the operation of amateur-built aircraft. Amateur-built aircraft are not required to meet the standardized certification requirements contained in Part 23.

¹³ Safety Board investigators determined that the accident pilot had about 70 minutes of pilot-in-command experience in this model airplane, not including the accident flight. The pilot's flight experience will be discussed later in this recommendation letter.

had avoided this problem by planning his flights in the airplane such that he never needed to operate the fuel selector valve handle in flight.

Safety Board investigators found that there are numerous experimental category airplanes that are flown without placards and markings on cockpit instruments and essential system controls, such as the fuel selector handle. Further, essential cockpit controls, including fuel selectors in amateur-built airplanes, are not required to be in standardized locations. The Board is concerned that pilots inexperienced in such airplanes may find it difficult to operate them without type-specific training (type-specific training will be discussed later in this recommendation letter).¹⁴

FAA Order 8130.2C, "Airworthiness Certification of Aircraft and Related Products," provides guidance to FAA aviation safety inspectors regarding the issuance of special airworthiness certificates and operating limitations for experimental aircraft. Paragraph 88(b) of this order describes inspections necessary to obtain special airworthiness certificates. It indicates that all instruments should be marked according to the approved flight manual. Advisory Circular (AC) 20-27D "Certification and Operation of Amateur-Built Aircraft," provides guidance to pilots on building, certifying, and operating amateur-built aircraft and describes the FAA's role in the certification process. Paragraph 12 of AC 20-27D states that the applicant should expect the FAA inspector or the designated airworthiness representative (DAR)¹⁵ to verify that all required markings are properly applied. The FAA order and the AC, however, do not explicitly require the inspection of placards or markings in the cockpit before issuing special airworthiness certificates. They also do not provide adequate guidance or evaluation concerning the inspection of the placement or operation of essential controls. Because accident data from a Safety Board study suggest that the ergonomics of cockpit control placement can be critical in the safe operation of airplanes,¹⁶ the Board is concerned that a lack of requirements for standardized placards, markings, or appropriate placement of essential system controls could jeopardize flight safety in experimental, amateur-built airplanes. Therefore, the Safety Board believes that the FAA should amend FAA Order 8130.2C to specify that, before the issuance of special airworthiness certificates, experimental, amateur-built airplanes should be inspected for needed placards and markings on cockpit instruments and for the appropriate placement and operation of

¹⁴ Safety Board staff found that the Glasair training syllabus directed the pilot to answer multiple questions concerning, among other subjects, fuel system descriptions, operations, and emergency procedures.

¹⁵ DARs are private persons designated by the FAA to act in its behalf in the inspection of aircraft and to issue airworthiness certificates.

¹⁶ A 1974 NTSB special study, U.S. General Aviation Accidents Involving Fuel Starvation (AAS-74-01) analyzed fuel starvation aircraft accidents from 1970 through 1972. Among the recommendations in the report, which were intended to reduce the number of fuel starvation accidents, the Safety Board asked the FAA to amend 14 CFR Part 23 to include specifications for standardizing fuel selector valve designs, displays, and modes of operation (A-74-39). This recommendation was classified "Closed—Acceptable Action" after the FAA changed Part 23. Currently, 14 CFR Part 23.777 addresses the physical placement of controls and states that "each fuel feed selector control must...be located and arranged so that the pilot can see and reach it without moving any seat or primary flight control when his seat is at any position in which it can be placed." The mapping of fuel selector control positions in accordance with natural expectations is addressed in 14 CFR Part 23.779, which requires that fuel selector control movement be consistent with tank selection (i.e., left for left tanks; right for right tanks).

essential system controls to ensure that they provide clear marking, easy access, and ease of operation.

The Safety Board notes that the requirement for an annual inspection (referred to as a condition inspection)¹⁷ of experimental, amateur-built airplanes is contained in a limitations letter attached to the special certificate of airworthiness.¹⁸ Paragraphs 141 and 142 of Order 8130.2C generally describe the issuance of experimental operating limitations,¹⁹ which always include the inspection requirements. The operating limitations state that the condition inspection shall be recorded in the aircraft maintenance records in accordance with the scope and detail of 14 CFR Part 43, Appendix D or other FAA-approved programs and that the condition inspection is equivalent to an annual inspection.

The operations limitations may require the use of placards and markings to ensure the safe operation of the aircraft. The Safety Board is not aware of any recurrent requirement to inspect placards and markings in the cockpit and on essential system controls to ensure that they display appropriate and accurate information.

The Safety Board is concerned about the lack of requirements to periodically inspect the placards, markings, and essential controls in experimental, amateur-built aircraft. Periodic inspection of these items is necessary to ensure that they consistently display appropriate and accurate information to the pilot for flight safety. Therefore, the Safety Board believes that the FAA should amend FAA Order 8130.2C to specify that inspection limitations be issued with special airworthiness certificates for amateur-built airplanes requiring that the annual condition inspection include an inspection for needed placards and markings on cockpit instruments and the appropriate operation of essential controls to ensure that they provide clear marking, easy access, and ease of operation.

Another concern of the Safety Board was the limited amount of transition training received by the accident pilot in the accident airplane. A review of the pilot's FAA airman and medical records indicated that he held a private pilot certificate with airplane ratings for single and multiengine land, single-engine sea, instrument airplane, glider, and a Lear Jet type rating. The pilot's logbook was not recovered after the accident; however, his total flight time reported on his last physical was 2,750 hours, including 15 hours in the preceding 6 months. The Safety Board's investigation revealed that the pilot purchased the accident airplane on September 27, 1997, and that his pilot-in-command experience in the airplane was limited to a 1/2-hour ground and flight checkout on the day before the accident and a 1-hour solo flight. According to an air traffic control communication tape, the duration of the checkout flight was only 10 minutes, and the pilot departed about 20 minutes later for a 1-hour solo flight to his home airport. The Safety Board learned that the pilot had been on three previous demonstration flights in Long-EZ airplanes (during all of which he occupied the rear seat) but could not determine how much, if

¹⁷ Condition inspection is defined in the Airworthiness Inspector's Handbook, FAA Order 8300.10, Chapter 25.

¹⁸ The limitations letter lists requirements for continued airworthiness.

¹⁹ The operating limitations are designed for each aircraft. The FAA inspector may impose any operational limitations deemed necessary in the interest of safety.

any, pilot training he received during these flights.²⁰ The Safety Board found no evidence of the pilot having any other flight experience in Long-EZ airplanes.

On the basis of his limited flight experience in this type of airplane, the Safety Board concludes that the pilot likely did not have the necessary knowledge and skills to efficiently operate it during the emergency circumstances of the accident flight. Had the pilot been more skilled in the operation of the flight controls and knowledgeable of the unusual fuel selector, the accident might have been avoided or the severity of the accident could have been reduced.²¹

The Safety Board is aware that some advanced,²² experimental, amateur-built airplane training organizations have published training syllabi. The Safety Board also notes that insurers²³ of amateur-built airplanes, similar to or more advanced than the Long-EZ, have sometimes required a training syllabus and detailed aircraft inspection as conditions for providing insurance coverage for the pilot/owner. The Safety Board has found that the accident rates for high performance, complex, and unusual aircraft may be substantially reduced by requiring pilot/owner-operators to undergo type-specific ground and flight training. For example, it was found that when formal flight and ground training was required for pilots of Piper PA-46 Malibu airplanes, the fatal accident rate in that airplane model was reduced.²⁴ Further, the Aviation Insurance Association (AIA) has reported that using and closely adhering to a specified training syllabus has considerably reduced the accident rate in the Glasair and Lancair experimental, amateur-built airplanes.²⁵ Additionally, the Safety Board found accident rates of Robinson R22 helicopters were substantially reduced when, in response to the Safety Board's recommendations, the FAA issued Special Federal Aviation Regulation (SFAR) 73 on February 23, 1995,

²⁰ According to the Rutan engineer who gave the first demonstration flight, the pilot said he had no previous flights in Long-EZ airplanes. Only one demonstration flight was in N555JD.

²¹ The in-flight manipulation of the fuel selector, the location and accuracy of the fuel quantity sight gauges, and using the installed fuel totalizer probably would have been included in formalized transition training.

²² "Advanced" experimental airplanes are typically faster, aerodynamically cleaner, and are more complex than most amateur-built aircraft. The Safety Board staff found three companies that sell kits for experimental, amateur-built airplanes and that provide formal, type-specific ground and flight training to the owner/pilots of these airplanes. The Glasair training plan provides for approved certificated flight instructors located in different areas of the country that will conduct the formal course of instruction to the pilot. The Lancair plan provides ground instruction at its factory and provides a factory test pilot to fly at the builder's location in the builder's airplane through the first 10 hours of the flight test program. The Velocity plan has east and west coast centers that provide formal ground and flight instruction. Safety Board staff found that each company, in conjunction with insurers, mandates its specific course of training. Each of these formal programs provides certification to the insurers of the experimental, amateur-built airplane when pilots complete the prescribed training.

²³ According to the AIA, accident rates for the Glasair and Lancair airplanes have dramatically dropped because of insurers requiring pilots' use of type-specific training syllabi.

²⁴ A spokesman for AVEMCO (a major aircraft insurer) reported to the Safety Board that, as a condition of insurance, his company requires that all PA-46 pilots (and pilots of other pressurized airplanes) attend formal training that includes completion of a type-specific training syllabus. These programs reportedly reduced the accident rates of these airplanes. The Safety Board's accident data show no PA-46 fatal accidents during 1992 and 1997, 1 in 1993, 2 in 1998, and 3 in 1994, 1995, and 1996, respectively. None of the accidents' probable causes is attributed to inadequate transition training.

²⁵ The AIA has reported that by requiring type-specific transition training in conjunction with the airplane manufacturer, the accident rates for those aircraft were significantly lowered.

promulgating special training, proficiency, and operational rules for pilots operating these helicopters.²⁶ The SFAR required specific training in this highly responsive helicopter before a pilot could operate it as the pilot-in-command.

A 1998 query showed that the FAA's aircraft database contains about 20,244 experimental, amateur-built aircraft, including 1,200 Long-EZ airplanes.²⁷ According to the EAA, about 8,000 additional aircraft were in the process of being built by amateur builders in 1997, and in the next few years, a significant number of amateur-built airplanes will be sold to non-builders. As previously mentioned, experimental, amateur-built aircraft are not required to be certificated to 14 CFR Part 23 certification standards and, therefore, may well have control locations, functions, and markings that do not conform to the original design plans. Because of these and other differences (such as performance and handling characteristics) between experimental, amateur-built aircraft and Part 23 aircraft, quality transition training²⁸ of pilots flying them is critical to their safe operation.

The Safety Board is aware of the EAA's Flight Advisor Program, which is designed to help amateur airplane builders safely perform their first flight. In this program, advisors with substantial flying/building experience offer free advice, videos, and written guidance to help make builders' first test flight a safe one. The advisors do not provide flight training but offer training suggestions and options for the pilot to consider. This program, which the EAA claims has resulted in reduced first-flight accident rates,²⁹ is generally known among EAA members but not among the general pilot population.

Such programs can provide an added margin of safety for pilots inexperienced in the operation of unusual or unique, non-Part 23-certificated aircraft. Unfortunately, no FAA ACs, pamphlets, or programs exist that require or encourage pilots who did not build their experimental category airplanes to receive type-specific transition flight training. FAA publications and programs also lack emphasis on the benefits of formalized syllabi for such transition training. The Safety Board concludes that an expanded flight advisor program could substantially reduce the experimental, amateur-built airplane accident rate. Therefore, the Safety Board believes that the FAA should establish, in conjunction with the EAA and the AIA, a cooperative program that strongly encourages pilots transitioning to unusual or unfamiliar amateur-built, experimental category airplanes to undergo formalized, type-specific transition training similar to that provided to pilots of some advanced, experimental, amateur-built airplanes.

²⁶ For more information, see NTSB Special Investigation Report, NTSB/SIR-96/03, Robinson Helicopter Company R22 Loss of Main Rotor Control Accidents, dated April 2, 1996.

²⁷ According to the EAA, 4,500 Long-EZ plans were sold. The EAA estimates that about 95,000 plans or kits have been sold to prospective amateur builders of all aircraft types in the past 10 years.

²⁸ The Safety Board considers quality transition training to be type-specific, formal transition training that adheres to a training syllabus.

²⁹ The EAA has reported significant accident rate reductions since the Flight Advisor program was started in 1995.

Therefore, the National Transportation Safety Board recommends that the Federal Aviation Administration:

Amend FAA Order 8130.2C to specify that, before the issuance of special airworthiness certificates, experimental, amateur-built airplanes should be inspected for needed placards and markings on cockpit instruments and for the appropriate placement and operation of essential system controls to ensure that they provide clear marking, easy access, and ease of operation. (A-99-5)

Amend FAA Order 8130.2C to specify that inspection limitations be issued with special airworthiness certificates for amateur-built airplanes requiring that the annual condition inspection include an inspection for needed placards and markings on cockpit instruments and the appropriate operation of essential controls to ensure that they provide clear marking, easy access, and ease of operation. (A-99-6)

Establish, in conjunction with the Experimental Aircraft Association and the Aviation Insurance Association, a cooperative program that strongly encourages pilots transitioning to unusual or unfamiliar amateur-built, experimental category airplanes to undergo formalized, type-specific transition training similar to that provided to pilots of some advanced, experimental, amateur-built airplanes. (A-99-7)

Also as a result of its investigation, the Safety Board issued Safety Recommendations A-99-8 to the AIA and A-99-9 to the EAA.

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in these recommendations.

By:



Jim Hall
Chairman

Enclosure

National Transportation Safety Board
Washington, D.C. 20594

Brief of Accident

Adopted 01/26/99

LAX98FA008
FILE NO. 1406 10/12/97 PACIFIC GROVE, CA AIRCRAFT REG NO. N555JD TIME (LOCAL) - 17:28 PDT

MAKE/MODEL	-ADRIAN DAVIS-LONG-EZ	CREW	FATAL	SERIOUS	MINOR/NONE
ENGINE MAKE/MODEL	-Lycoming O-320-E3D	PASS	1	0	0
AIRCRAFT DAMAGE	-Destroyed		0	0	0
NUMBER OF ENGINES	-1				
OPERATING CERTIFICATES	-NONE				
TYPE OF FLIGHT OPERATION	-Personal				
REGULATION FLIGHT CONDUCTED UNDER	-14 CFR 91				
HOMEBUILT					

LAST DEPARTURE POINT DESTINATION	- MONTEREY, CA - Local	CONDITION OF LIGHT	- Daylight
AIRPORT PROXIMITY	- Off airport/airstrip	WEATHER INFO SOURCE	- Weather observation facility
AIRPORT NAME	- MONTEREY PENINSULA	BASIC WEATHER	- Visual (VMC)
RUNWAY IDENTIFICATION	- 28L	LOWEST CEILING	- None
RUNWAY LENGTH/WIDTH (Feet)	- 7598/150	VISIBILITY	- 50.000 SM
RUNWAY SURFACE	- Asphalt	WIND DIR/SPEED	- 300 /005 KTS
RUNWAY SURFACE CONDITION	- Dry	TEMPERATURE (F)	- 63
		OBSTR TO VISION	- None
		PRECIPITATION	- None

PILOT-IN-COMMAND	AGE - 53	FLIGHT TIME (HOURS)	
CERTIFICATES/RATINGS		TOTAL ALL AIRCRAFT	- 2750
Private		LAST 90 DAYS	- Unk/NR
Single-engine land, Multiengine land, Single-engine sea		TOTAL MAKE/MODEL	- 2
Glider		TOTAL INSTRUMENT TIME	- Unk/NR
INSTRUMENT RATINGS			
Airplane			

The pilot had recently purchased the experimental, amateur-built Long-EZ airplane, which had a fuel system that differed from the designer's plans. The original builder had modified the fuel system by relocating the fuel selector handle from a position between the front pilot's legs to a position behind & above his (or her) left shoulder. There were no markings for the operating positions of the fuel selector handle, which were up (for off), down (for the right tank), and to the right (for the left tank). This deviation from the original design plans did not require FAA approval, nor did it require a placard to indicate such change from the original design. On 10/11/97 at Santa Maria, CA, the pilot received a 1/2-hour flight and ground checkout in the airplane by another Long-EZ pilot. The checkout pilot reported that the pilot needed a seatback cushion to be in position to reach the rudder pedals, and that he had difficulty reaching the fuel selector handle while seated with the cushion added. The pilot then departed on a 1-hour

flight to his home base at Monterey with an estimated 12.5 gallons of fuel in the right tank & 0.2 gallons in the left tank. The checkout pilot estimated about 9 gallons of fuel were needed for the flight, and he noted the fuel selector was positioned to the right tank before departure. On 10/12/97 (the next day), a maintenance technician assisted the pilot in preparing for another flight. During preflight, the pilot was not observed to visually check the fuel. The technician noted that when the pilot was seated in the airplane, he had difficulty reaching the fuel selector handle. Also, he gave the pilot a mirror to look over his shoulder to see the unmarked, non-linear, fuel sight gauges, which were located in the rear cockpit. The technician estimated the available fuel and advised the pilot that the left tank indicated less than 1/4 full and that the right tank indicated less than 1/2 full. He said his estimate was based on the assumption that the gauges were accurate and linear. The pilot declined an offer for additional fuel, saying he would only be airborne about 1 hour and did not need fuel. The technician observed that before the engine was started, the fuel selector handle was in a vertical position; however, he did not note whether it was up (off) or down (right tank). As the technician went to the hangar, he heard the engine start & run for a short time, then quit. He saw the pilot turn in the seat toward the fuel selector handle, then the pilot motioned with his hand that things were all right. The technician did not observe whether the pilot had repositioned the fuel selector. The pilot restarted the engine, taxied, took off, and performed three touch-and-go landings in a span of about 26 minutes, followed by a straight-out departure to the west. Ground witnesses saw the airplane in straight and level flight about 350 to 500 feet over a residential area, then they heard a reduction of engine noise. The airplane was seen to pitch slightly nose up; then it banked sharply to the right & descended nose first into the ocean. The major structural components of the airframe were found fragmented on the ocean floor near the engine, but no preimpact part failure was found. The fuel selector valve was found in an intermediate position, about 1/3 open between the engine feed line and the right tank, and about 2-4 $\frac{1}{2}$ open to the left tank. Tests using another engine showed that the engine could be operated at full power with the selector in the as-found position; however, when the cap was removed from the left port (simulating the effect of an empty left tank), fuel pressure dropped to less than 1/2; & within a few seconds, the engine lost power. Conditions were simulated using another Long-EZ to evaluate the maneuver required to switch tanks from the front seat. The simulation revealed that 4 actions were required to change the fuel selector in flight: 1) Remove pilot's hand from the control stick; 2) Loosen shoulder harness; 3) Rotate upper body to the extreme left to reach the fuel selector handle; & 4) Rotate the handle to a non-marked (not logically oriented) position. During the evaluation, investigators noted a natural reaction for the pilot's right foot to depress the right rudder pedal when turning in the seat to reach the fuel selector handle. With the right rudder depressed in flight, the airplane would pitch up slightly & bank to the right.

Brief of Accident (Continued)

LAX96FA008

FILE NO.1406 10/12/97 PACIFIC GROVE, CA AIRCRAFT REG NO. N555JD TIME (LOCAL) - 17:28 PDT

Occurrence# 1 LOSS OF ENGINE POWER (TOTAL) - NONMECHANICAL
Phase of operation CRUISE

Findings

1. FUEL SYSTEM, SELECTOR/VALVE
2. ACFT/EQUIP, INADEQUATE CONTROL LOCATION - OWNER/BUILDER
3. FUEL SYSTEM, SELECTOR/VALVE - UNMARKED
4. ENGINE INSTRUMENTS, FUEL QUANTITY GAGE - INADEQUATE
5. ENGINE INSTRUMENTS, FUEL QUANTITY GAGE - UNMARKED
6. PREFLIGHT PLANNING/PREPARED - INADEQUATE - PILOT IN COMMAND
7. REFUELING - NOT PERFORMED - PILOT IN COMMAND
8. FUEL TANK SELECTOR POSITION - IMPROPER - PILOT IN COMMAND
9. FLUID, FUEL - STARVATION/EXHAUSTION

Occurrence# 2 LOSS OF CONTROL - IN FLIGHT
Phase of operation EMERGENCY DESCENT/LANDING

Findings

10. REMEDIAL ACTION - ATTEMPTED
11. RUDDER - INADVERTENT ACTIVATION - PILOT IN COMMAND
12. DIVERTED ATTENTION - PILOT IN COMMAND
13. INADEQUATE TRANSITION/UPGRADE TRAINING
14. LACK OF TOTAL EXPERIENCE IN TYPE OF AIRCRAFT - PILOT IN COMMAND

Occurrence# 3 IN FLIGHT COLLISION WITH TERRAIN/WATER
Phase of operation DESCENT - UNCONTROLLED

Findings

15. TERRAIN CONDITION - WATER

The National Transportation Safety Board determines the probable cause(s) of this accident was: the pilot's diversion of attention from the operation of the airplane and his inadvertent application of right rudder that resulted in the loss of airplane control while attempting to manipulate the fuel selector handle. Also, the Board determined that the pilot's inadequate preflight planning and preparation, specifically his failure to refuel the airplane, was causal. The Board determined that the builder's decision to locate the unmarked fuel selector handle in a hard-to-access position, unmarked fuel quantity sight gauges, inadequate transition training by the pilot, and his lack of total experience in this type of airplane were factors in the accident.



National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: February 3, 1999

In reply refer to: A-99-8

Mr. John Donica
Executive Director
Aviation Insurance Association
899 South College Mall Road, #375
Bloomington, Indiana 47401

On October 12, 1997, about 1728 Pacific daylight time, an experimental category, amateur-built Adrian Davis¹ Long-EZ airplane, N555JD, crashed into the Pacific Ocean near Pacific Grove, California. Air traffic control communications indicated that the airplane had departed from the Monterey Peninsula Airport's runway 28L about 1712, and the pilot performed three touch-and-go landings and departed to the west moments before the accident. Witnesses reported that they heard engine popping and a reduction in engine noise before the accident. The pilot made no distress calls. The pilot was killed, and the airplane was destroyed.

An airport maintenance technician helped the pilot push the airplane out of the hangar before the accident flight and was present during the preflight check. The technician said he told the pilot that less than a quarter tank of fuel was available in the left tank and less than half a tank of fuel was available in the right tank. The technician estimated the fuel quantity based on the assumption that the presentations on the unmarked sight gauges were linear. However, Long-EZ fuel tank sight gauges are not linear, and examination of other Long-EZ sight gauges revealed that the actual fuel on-board the airplane would have been much lower than the technician's estimate. The fuel tank sight gauges were not visible from the front cockpit. The technician loaned the pilot a shop inspection mirror so it would be possible for the pilot to see the fuel tank sight gauges in flight. The pilot told the technician that he did not wish to refuel the airplane.

The technician said he heard the engine start and run for a short time and quit. Watching from the hangar, he saw the pilot turn in the front cockpit toward the fuel selector handle behind his left shoulder. Shortly afterward, the technician heard the engine restarted. The pilot signaled an "okay" to the technician and taxied toward the runway. After the airplane departed the traffic

¹ The Federal Aviation Administration (FAA) issues experimental airworthiness certificates for amateur-built aircraft with the original builder's name as the manufacturer. Any subsequent owner may change the registration number but not the Certificate of Airworthiness. Hence, the builder's name appears on the Certificate of Airworthiness.

pattern to the west, witnesses reported that the airplane climbed to 350 to 500 feet and was in level flight when, after the reduction in engine noise, it pitched slightly nose-up, entered a steep right bank, and descended nose-first into the ocean.

Safety Board investigators determined that the weight and center of gravity of the accident airplane were within the original planned limits for the Long-EZ and would not have affected the flight or stall characteristics of the airplane. Based on the airplane's fueling history, the technician's observations of the fuel levels at engine start, and the normal fuel consumption rates of the airplane's Lycoming O-320-E3D engine, the airplane would have had about 3 1/2 gallons of fuel available from the left tank and about 6 1/2 gallons of fuel available from the right tank. The Safety Board found that witness statements were consistent with the checkout pilot's description of postflight engine shut-down² and concluded that the engine lost power because of fuel starvation or exhaustion.³

The Long-EZ was designed by Rutan Aircraft Factory and amateur-built from the Rutan plans as a single-engine, tandem cockpit, swept-wing, canard-equipped⁴ airplane with laminar flow airfoils.⁵ The engine is mounted aft of the cabin, and both cockpits have pitch and roll side-stick controls.

The all-composite⁶ airplane has a canard with elevators for pitch control. The swept wings have taper and twist and have winglets installed at the tips. According to technicians from the Experimental Aircraft Association (EAA), the rudder system used in the Long-EZ is very sensitive⁷ in low-speed flight. According to the former Rutan chief engineer, the airplane has a substantial glide ratio due to its aerodynamically clean design but will pitch up and roll right when the airspeed is slow and the right rudder is depressed. When the airspeed is higher, he stated that roll rates are much higher and that it is possible to aileron-roll the airplane from rudder application only (ailerons neutral).

According to the Long-EZ owner's manual, the airplane has good flight characteristics at minimum speed. The manual describes "stalls" as maneuvers that result in increased aft stick force or mild pitch or roll oscillations. Spin attempts result in a spiral that reportedly can be recovered by neutralizing rudder and pulling out normally. The Long-EZ design incorporates many high performance features but would not be considered "high performance" by Federal

² The checkout pilot told Safety Board investigators that when the engine was stopped by closing the mixture (shutting off the fuel supply) at the end of a flight, loud popping normally occurred.

³ For more information, see Brief of Accident #LAX98FA008 (enclosed).

⁴ A canard is a lifting airfoil located in the front portion of an airplane that eliminates the need for a tail-mounted horizontal stabilizer.

⁵ Laminar flow airfoils are used in high performance, complex aircraft such as the Beech Starship. The airfoil construction minimizes drag but is sensitive to boundary layer separation (stall).

⁶ The Long-EZ airplane is constructed of shaped foam and fiberglass/epoxy materials.

⁷ The rudder system in the Long-EZ comprises two independent, outward acting rudders on the rear of the winglets. Activation in low speed flight is very easy; however, the owners manual cautions against inadvertent use because a substantial yaw will result.

Aviation Administration (FAA) definition⁸ because the airplane has no flaps or controllable pitch propeller. Nonetheless, its laminar flow airfoils have greater lift-to-drag ratios than most general aviation airplanes. Because the airplane has no flaps, its landing speeds are greater than many small airplanes, and it has a wings level, power off stall speed of about 71 mph.⁹

The Long-EZ airplane has two 26-gallon fuel tanks, one at each wing root. Fuel quantity is determined by viewing the rear cockpit sight gauges. N555JD was also equipped with a fuel totalizer.¹⁰ Fuel is selected from the left or the right tank by turning a fuel selector handle. According to the Rutan design, the fuel selector handle is to be located just aft of the nose wheel position window between the pilot's legs and is oriented toward the right to select the right tank, left to select the left tank, and another quarter turn to the left to select the "Off" position. A placard associated with the Rutan design clearly identifies the fuel selector handle positions.

The amateur builder of N555JD modified the fuel system design by locating the fuel selector handle on the left side of the bulkhead that forms the front cockpit seat back. It was positioned approximately behind the front-seat pilot's left shoulder (see figure 1). The builder also changed the orientation of the handle so that upward selected "Off," right selected the left tank, and downward selected the right tank. The corresponding 3-position fuel selector valve was installed inside the rear cockpit on the front of the engine firewall just behind the rear seat and was connected to the selector handle via two torque tubes and a universal joint. The selector handle was about 4 feet forward of the fuel selector valve. No placard or marking existed (nor was it required) on the fuel selector handle base that would have indicated to the pilot its operating position. Further, as has been stated, the sight gauges were not marked to quantify the amount of fuel in the tanks.

⁸ The FAA defines "high performance" as an airplane that has an engine with greater than 200 horsepower or that has retractable landing gear, flaps, and a controllable pitch propeller (14 Code of Federal Regulations (CFR) Part 61.31 (e)).

⁹ The maximum stall speed allowed for aircraft certificated under 14 CFR Part 23 is 61 knots (70 mph).

¹⁰ Although the accident airplane was equipped with sight gauges, which were part of the original design, it also had a fuel totalizer installed in the front instrument panel that required pilot entry of the starting fuel amount. Witness statements provide no evidence that the totalizer was used, and the checkout pilot stated he was not familiar with it and did not provide any instruction on its use.

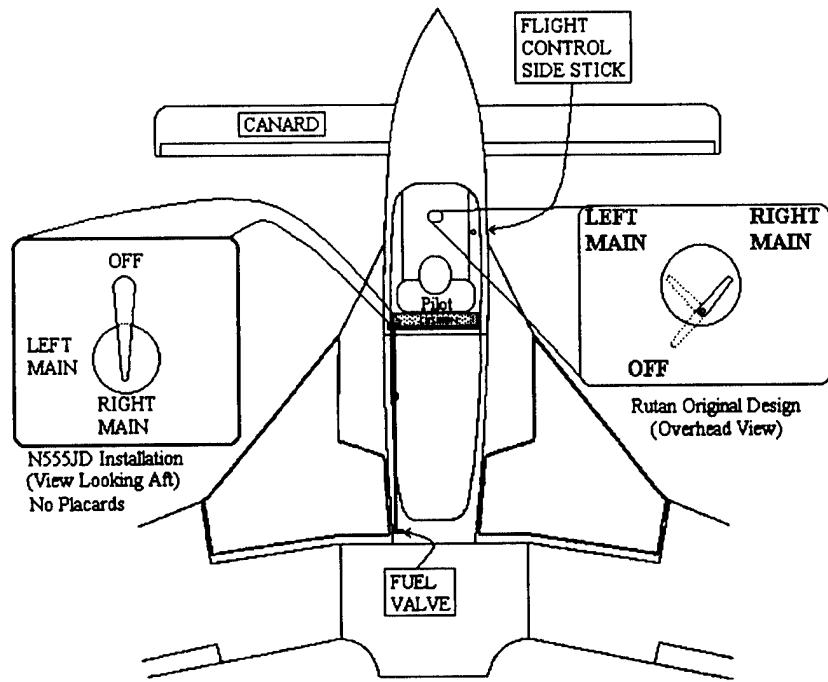


Figure 1—Comparison of fuel selector handle locations in Long-EZ

N555JD vs. Original design

The flight control side sticks in both cockpits were installed in armrests on the right side of the cockpits, measured about 6 inches high, and were similar in function to a conventional control stick. During the postaccident investigation, simulation by Safety Board staff showed that the front-seat pilot in the accident airplane would have had to loosen his shoulder harness, completely release the flight control stick, turn in his seat, and stretch to his left when reaching over the left shoulder with his right hand to change the position of the fuel selector handle on the accident Long-EZ airplane. The Safety Board investigator, in every simulation, inadvertently applied right rudder when turning his body and reaching for the fuel selector handle. This finding concerned the Safety Board because the design change that moved the fuel selector handle introduced a safety hazard in N555JD. On the basis of the accident circumstances and witness accounts, the Board concluded that the accident pilot probably inadvertently applied right rudder while manipulating the fuel selector, precipitating the loss of control that preceded the accident.

The fuel selector valve assembly from the accident airplane was found in an intermediate position; the selector valve port from the right tank fuel supply line was about 33 percent open to the engine feed line and the left was about 2 to 4 percent open to the engine feed line. An engine test run in a test cell showed that full power could be attained (with fuel in both tanks) with the selector valve in the "as found" position. However, with fuel in only one tank and the other fuel

line open to the atmosphere to simulate an empty tank, the engine lost power with the fuel selector valve in the "as found" position. The position of the fuel selector handle from the accident airplane could not be determined because of damage to the torque tubes between the valve and the selector handle.

Postaccident examination of the engine revealed no mechanical failures, and internal continuity of the drive train components was established. The magneto¹¹ was tested and produced a normal spark. The fuel lines had no leaks or blockages. The evidence indicated that the engine was capable of producing normal power if sufficient fuel was supplied to it.

The Safety Board determined that the probable cause of the accident was the pilot's diversion of attention from the operation of the airplane and his inadvertent application of right rudder that resulted in the loss of airplane control while attempting to manipulate the fuel selector handle. Also, the Board determined that the pilot's inadequate preflight planning and preparation, specifically his failure to refuel the airplane, was causal. The Board determined that the builder's decision to locate the unmarked fuel selector handle in a hard-to-access position, unmarked fuel quantity sight gauges, inadequate transition training by the pilot, and his lack of total experience in the type of airplane were factors in the accident.

N555JD had a special airworthiness certificate in the experimental category¹² that was issued on May 5, 1987. The airplane had been flown about 850 hours and had been sold two times since its construction. Because N555JD was an experimental, amateur-built airplane, specific deviations from the original plans did not require FAA approval nor was a placard required to identify fuel selector valve positions or to indicate that there had been a change in the airplane's design. However, the overall design is evaluated for safety and airworthiness by the FAA prior to issuing the experimental airworthiness certificate.

The Safety Board is concerned that the pilot of N555JD, who had minimal¹³ pilot-in-command experience in the accident airplane, may not have been adequately familiar with the operating positions of the unmarked fuel selector handle. This is of special concern because in its modified location and orientation, the fuel selector handle's operating positions would have been less intuitively obvious than if it had been installed as originally designed. Also, demonstrations indicated that the fuel selector handle was out of the accident pilot's view and in an awkward position that a pilot of similar height as the accident pilot (5' 10") could not operate without releasing the flight control stick. An interview with the checkout pilot revealed that he

¹¹ This engine had one magneto and one electronic ignition installed. The spark plugs showed evidence of normal ignition, and the magneto functioned normally when its impulse-coupling was rotated by hand. The electronic ignition was not tested.

¹² Title 14 CFR 21.191 "Experimental Certificates," allows experimental airworthiness certificates to be issued for, among other purposes, the operation of amateur-built aircraft. Amateur-built aircraft are not required to meet the standardized certification requirements contained in Part 23.

¹³ Safety Board investigators determined that the accident pilot had about 70 minutes of pilot-in-command experience in this model airplane, not including the accident flight. The pilot's flight experience will be discussed later in this recommendation letter.

had avoided this problem by planning his flights in the airplane such that he never needed to operate the fuel selector valve handle in flight.

Safety Board investigators found that there are numerous experimental category airplanes that are flown without placards and markings on cockpit instruments and essential system controls, such as the fuel selector handle. Further, essential cockpit controls, including fuel selectors in amateur-built airplanes, are not required to be in standardized locations. The Board is concerned that pilots inexperienced in such airplanes may find it difficult to operate them without type-specific training (type-specific training will be discussed later in this recommendation letter).¹⁴

FAA Order 8130.2C, "Airworthiness Certification of Aircraft and Related Products," provides guidance to FAA aviation safety inspectors regarding the issuance of special airworthiness certificates and operating limitations for experimental aircraft. Paragraph 88(b) of this order describes inspections necessary to obtain special airworthiness certificates. It indicates that all instruments should be marked according to the approved flight manual. Advisory Circular (AC) 20-27D "Certification and Operation of Amateur-Built Aircraft," provides guidance to pilots on building, certifying, and operating amateur-built aircraft and describes the FAA's role in the certification process. Paragraph 12 of AC 20-27D states that the applicant should expect the FAA inspector or the designated airworthiness representative (DAR)¹⁵ to verify that all required markings are properly applied. The FAA order and the AC, however, do not explicitly require the inspection of placards or markings in the cockpit before issuing special airworthiness certificates. They also do not provide adequate guidance or evaluation concerning the inspection of the placement or operation of essential controls. Because accident data from a Safety Board study suggest that the ergonomics of cockpit control placement can be critical in the safe operation of airplanes,¹⁶ the Board is concerned that a lack of requirements for standardized placards, markings, or appropriate placement of essential system controls could jeopardize flight safety in experimental, amateur-built airplanes. Therefore, the Safety Board believes that the FAA should amend FAA Order 8130.2C to specify that, before the issuance of special airworthiness certificates, experimental, amateur-built airplanes should be inspected for needed placards and markings on cockpit instruments and for the appropriate placement and operation of

¹⁴ Safety Board staff found that the Glasair training syllabus directed the pilot to answer multiple questions concerning, among other subjects, fuel system descriptions, operations, and emergency procedures.

¹⁵ DARs are private persons designated by the FAA to act in its behalf in the inspection of aircraft and to issue airworthiness certificates.

¹⁶ A 1974 NTSB special study, U.S. General Aviation Accidents Involving Fuel Starvation (AAS-74-01) analyzed fuel starvation aircraft accidents from 1970 through 1972. Among the recommendations in the report, which were intended to reduce the number of fuel starvation accidents, the Safety Board asked the FAA to amend 14 CFR Part 23 to include specifications for standardizing fuel selector valve designs, displays, and modes of operation (A-74-39). This recommendation was classified "Closed—Acceptable Action" after the FAA changed Part 23. Currently, 14 CFR Part 23.777 addresses the physical placement of controls and states that "each fuel feed selector control must...be located and arranged so that the pilot can see and reach it without moving any seat or primary flight control when his seat is at any position in which it can be placed." The mapping of fuel selector control positions in accordance with natural expectations is addressed in 14 CFR Part 23.779, which requires that fuel selector control movement be consistent with tank selection (i.e., left for left tanks; right for right tanks).

essential system controls to ensure that they provide clear marking, easy access, and ease of operation.

The Safety Board notes that the requirement for an annual inspection (referred to as a condition inspection)¹⁷ of experimental, amateur-built airplanes is contained in a limitations letter attached to the special certificate of airworthiness.¹⁸ Paragraphs 141 and 142 of Order 8130.2C generally describe the issuance of experimental operating limitations,¹⁹ which always include the inspection requirements. The operating limitations state that the condition inspection shall be recorded in the aircraft maintenance records in accordance with the scope and detail of 14 CFR Part 43, Appendix D or other FAA-approved programs and that the condition inspection is equivalent to an annual inspection.

The operations limitations may require the use of placards and markings to ensure the safe operation of the aircraft. The Safety Board is not aware of any recurrent requirement to inspect placards and markings in the cockpit and on essential system controls to ensure that they display appropriate and accurate information.

The Safety Board is concerned about the lack of requirements to periodically inspect the placards, markings, and essential controls in experimental, amateur-built aircraft. Periodic inspection of these items is necessary to ensure that they consistently display appropriate and accurate information to the pilot for flight safety. Therefore, the Safety Board believes that the FAA should amend FAA Order 8130.2C to specify that inspection limitations be issued with special airworthiness certificates for amateur-built airplanes requiring that the annual condition inspection include an inspection for needed placards and markings on cockpit instruments and the appropriate operation of essential controls to ensure that they provide clear marking, easy access, and ease of operation.

Another concern of the Safety Board was the limited amount of transition training received by the accident pilot in the accident airplane. A review of the pilot's FAA airman and medical records indicated that he held a private pilot certificate with airplane ratings for single and multiengine land, single-engine sea, instrument airplane, glider, and a Lear Jet type rating. The pilot's logbook was not recovered after the accident; however, his total flight time reported on his last physical was 2,750 hours, including 15 hours in the preceding 6 months. The Safety Board's investigation revealed that the pilot purchased the accident airplane on September 27, 1997, and that his pilot-in-command experience in the airplane was limited to a 1/2-hour ground and flight checkout on the day before the accident and a 1-hour solo flight. According to an air traffic control communication tape, the duration of the checkout flight was only 10 minutes, and the pilot departed about 20 minutes later for a 1-hour solo flight to his home airport. The Safety Board learned that the pilot had been on three previous demonstration flights in Long-EZ airplanes (during all of which he occupied the rear seat) but could not determine how much, if

¹⁷ Condition inspection is defined in the Airworthiness Inspector's Handbook, FAA Order 8300.10, Chapter 25.

¹⁸ The limitations letter lists requirements for continued airworthiness.

¹⁹ The operating limitations are designed for each aircraft. The FAA inspector may impose any operational limitations deemed necessary in the interest of safety.

any, pilot training he received during these flights.²⁰ The Safety Board found no evidence of the pilot having any other flight experience in Long-EZ airplanes.

On the basis of his limited flight experience in this type of airplane, the Safety Board concludes that the pilot likely did not have the necessary knowledge and skills to efficiently operate it during the emergency circumstances of the accident flight. Had the pilot been more skilled in the operation of the flight controls and knowledgeable of the unusual fuel selector, the accident might have been avoided or the severity of the accident could have been reduced.²¹

The Safety Board is aware that some advanced,²² experimental, amateur-built airplane training organizations have published training syllabi. The Safety Board also notes that insurers²³ of amateur-built airplanes, similar to or more advanced than the Long-EZ, have sometimes required a training syllabus and detailed aircraft inspection as conditions for providing insurance coverage for the pilot/owner. The Safety Board has found that the accident rates for high performance, complex, and unusual aircraft may be substantially reduced by requiring pilot/owner-operators to undergo type-specific ground and flight training. For example, it was found that when formal flight and ground training was required for pilots of Piper PA-46 Malibu airplanes, the fatal accident rate in that airplane model was reduced.²⁴ Further, the Aviation Insurance Association (AIA) has reported that using and closely adhering to a specified training syllabus has considerably reduced the accident rate in the Glasair and Lancair experimental, amateur-built airplanes.²⁵ Additionally, the Safety Board found accident rates of Robinson R22 helicopters were substantially reduced when, in response to the Safety Board's recommendations, the FAA issued Special Federal Aviation Regulation (SFAR) 73 on February 23, 1995,

²⁰ According to the Rutan engineer who gave the first demonstration flight, the pilot said he had no previous flights in Long-EZ airplanes. Only one demonstration flight was in N555JD.

²¹ The in-flight manipulation of the fuel selector, the location and accuracy of the fuel quantity sight gauges, and using the installed fuel totalizer probably would have been included in formalized transition training.

²² "Advanced" experimental airplanes are typically faster, aerodynamically cleaner, and are more complex than most amateur-built aircraft. The Safety Board staff found three companies that sell kits for experimental, amateur-built airplanes and that provide formal, type-specific ground and flight training to the owner/pilots of these airplanes. The Glasair training plan provides for approved certificated flight instructors located in different areas of the country that will conduct the formal course of instruction to the pilot. The Lancair plan provides ground instruction at its factory and provides a factory test pilot to fly at the builder's location in the builder's airplane through the first 10 hours of the flight test program. The Velocity plan has east and west coast centers that provide formal ground and flight instruction. Safety Board staff found that each company, in conjunction with insurers, mandates its specific course of training. Each of these formal programs provides certification to the insurers of the experimental, amateur-built airplane when pilots complete the prescribed training.

²³ According to the AIA, accident rates for the Glasair and Lancair airplanes have dramatically dropped because of insurers requiring pilots' use of type-specific training syllabi.

²⁴ A spokesman for AVEMCO (a major aircraft insurer) reported to the Safety Board that, as a condition of insurance, his company requires that all PA-46 pilots (and pilots of other pressurized airplanes) attend formal training that includes completion of a type-specific training syllabus. These programs reportedly reduced the accident rates of these airplanes. The Safety Board's accident data show no PA-46 fatal accidents during 1992 and 1997, 1 in 1993, 2 in 1998, and 3 in 1994, 1995, and 1996, respectively. None of the accidents' probable causes is attributed to inadequate transition training.

²⁵ The AIA has reported that by requiring type-specific transition training in conjunction with the airplane manufacturer, the accident rates for those aircraft were significantly lowered.

promulgating special training, proficiency, and operational rules for pilots operating these helicopters.²⁶ The SFAR required specific training in this highly responsive helicopter before a pilot could operate it as the pilot-in-command.

A 1998 query showed that the FAA's aircraft database contains about 20,244 experimental, amateur-built aircraft, including 1,200 Long-EZ airplanes.²⁷ According to the EAA, about 8,000 additional aircraft were in the process of being built by amateur builders in 1997, and in the next few years, a significant number of amateur-built airplanes will be sold to non-builders. As previously mentioned, experimental, amateur-built aircraft are not required to be certificated to 14 CFR Part 23 certification standards and, therefore, may well have control locations, functions, and markings that do not conform to the original design plans. Because of these and other differences (such as performance and handling characteristics) between experimental, amateur-built aircraft and Part 23 aircraft, quality transition training²⁸ of pilots flying them is critical to their safe operation.

The Safety Board is aware of the EAA's Flight Advisor Program, which is designed to help amateur airplane builders safely perform their first flight. In this program, advisors with substantial flying/building experience offer free advice, videos, and written guidance to help make builders' first test flight a safe one. The advisors do not provide flight training but offer training suggestions and options for the pilot to consider. This program, which the EAA claims has resulted in reduced first-flight accident rates,²⁹ is generally known among EAA members but not among the general pilot population.

Such programs can provide an added margin of safety for pilots inexperienced in the operation of unusual or unique, non-Part 23-certificated aircraft. Unfortunately, no FAA ACs, pamphlets, or programs exist that require or encourage pilots who did not build their experimental category airplanes to receive type-specific transition flight training. FAA publications and programs also lack emphasis on the benefits of formalized syllabi for such transition training. The Safety Board concludes that an expanded flight advisor program could substantially reduce the experimental, amateur-built airplane accident rate. Therefore, the Safety Board believes that the AIA should establish, in conjunction with the FAA and the EAA, a cooperative program that strongly encourages pilots transitioning to unusual or unfamiliar amateur-built, experimental category airplanes to undergo formalized, type-specific transition training similar to that provided to pilots of some advanced, experimental, amateur-built airplanes.

²⁶ For more information, see NTSB Special Investigation Report, NTSB/SIR-96/03, Robinson Helicopter Company R22 Loss of Main Rotor Control Accidents, dated April 2, 1996.

²⁷ According to the EAA, 4,500 Long-EZ plans were sold. The EAA estimates that about 95,000 plans or kits have been sold to prospective amateur builders of all aircraft types in the past 10 years.

²⁸ The Safety Board considers quality transition training to be type-specific, formal transition training that adheres to a training syllabus.

²⁹ The EAA has reported significant accident rate reductions since the Flight Advisor program was started in 1995.

Therefore, the National Transportation Safety Board recommends that the Aviation Insurance Association:

Establish, in conjunction with the Federal Aviation Administration and the Experimental Aircraft Association, a cooperative program that strongly encourages pilots transitioning to unusual or unfamiliar amateur-built, experimental category airplanes to undergo formalized, type-specific transition training similar to that provided to pilots of some advanced, experimental, amateur-built airplanes. (A-99-8)

Also as a result of its investigation, the Safety Board issued Safety Recommendations A-99-5 through -7 to the FAA and A-99-9 to the EAA.

The National Transportation Safety Board is an independent Federal agency with the statutory responsibility "...to promote transportation safety by conducting independent accident investigations and by formulating safety improvement recommendations" (Public Law 93-633). The Safety Board is vitally interested in any actions taken as a result of its safety recommendations and would appreciate a response from you regarding action taken or contemplated with respect to the recommendation in this letter. Please refer to Safety Recommendation A-99-8 in your reply.

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in this recommendation.

By: 
Jim Hall
Chairman

Enclosure

National Transportation Safety Board
Washington, D.C. 20594

Brief of Accident

Adopted 01/26/99

LAX98FA008
FILE NO. 1406 10/12/97 PACIFIC GROVE, CA AIRCRAFT REG NO. N555UD TIME (LOCAL) - 17:28 PDT

MAKE/MODEL	-ADRIAN DAVIS-LONG-EZ	CREW	FATAL 1	SERIOUS 0	MINOR/NONE 0
ENGINE MAKE/MODEL	-Lycoming O-320-E3D	PASS	0	0	0
AIRCRAFT DAMAGE	-Destroyed				
NUMBER OF ENGINES	-1				
OPERATING CERTIFICATES	-NONE				
TYPE OF FLIGHT OPERATION	-Personal				
REGULATION FLIGHT CONDUCTED UNDER	-14 CFR 91				
HOMEBUILT					

LAST DEPARTURE POINT DESTINATION	- MONTEREY, CA - Local	CONDITION OF LIGHT - Daylight
AIRPORT PROXIMITY	- Off airport/airstrip	WEATHER INFO SOURCE - Weather observation facility
AIRPORT NAME	- MONTEREY PENINSULA	BASIC WEATHER - Visual (VMC)
RUNWAY IDENTIFICATION	- 28L	LOWEST CEILING - None
RUNWAY LENGTH/WIDTH (Feet)	- 7598/150	VISIBILITY - 50,000 SM
RUNWAY SURFACE	- Asphalt	WIND DIR/SPEED - 300 / 005 KTS
RUNWAY SURFACE CONDITION	- Dry	TEMPERATURE (F) - 63
		OBSTR TO VISION - None
		PRECIPITATION - None

PILOT-IN-COMMAND	AGE - 53	FLIGHT TIME (Hours)
CERTIFICATES/RATINGS		TOTAL ALL AIRCRAFT - 2750
Private		LAST 90 DAYS - Unk/NR
Single-engine land, Multiengine land, Single-engine sea		TOTAL MAKE/MODEL - 2
Glider		TOTAL INSTRUMENT TIME - Unk/NR
INSTRUMENT RATINGS		
Airplane		

The pilot had recently purchased the experimental, amateur-built Long-EZ airplane, which had a fuel system that differed from the designer's plans. The original builder had modified the fuel system by relocating the fuel selector handle from a position between the front pilot's legs to a position behind & above his (or her) left shoulder. There were no markings for the operating positions of the fuel selector handle, which were up (for off), down (for the right tank), and to the right (for the left tank). This deviation from the original design plans did not require FAA approval, nor did it require a placard to indicate such change from the original design. On 10/11/97 at Santa Maria, CA, the pilot received a 1/2-hour flight and ground checkout in the airplane by another Long-EZ pilot. The checkout pilot reported that the pilot needed a seatback cushion to be in position to reach the rudder pedals, and that he had difficulty reaching the fuel selector handle while seated with the cushion added. The pilot then departed on a 1-hour

flight to his home base at Monterey with an estimated 12.5 gallons of fuel in the right tank & 6.5 gallons in the left tank. The checkout pilot estimated about 9 gallons of fuel were needed for the flight, and he noted the fuel selector was positioned to the right tank before departure. On 10/12/97 (the next day), a maintenance technician assisted the pilot in preparing for another flight. During preflight, the pilot was not observed to visually check the fuel. The technician noted that when the pilot was seated in the airplane, he had difficulty reaching the fuel selector handle. Also, he gave the pilot a mirror to look over his shoulder to see the unmarked, non-linear, fuel sight gauges, which were located in the rear cockpit. The technician estimated the available fuel and advised the pilot that the left tank indicated less than 1/4 full and that the right tank indicated less than 1/2 full. He said his estimate was based on the assumption that the gauges were accurate and linear. The pilot declined an offer for additional fuel, saying he would only be airborne about 1 hour and did not need fuel. The technician observed that before the engine was started, the fuel selector handle was in a vertical position; however, he did not note whether it was up (off) or down (right tank). As the technician went to the hangar, he heard the engine start & run for a short time, then quit. He saw the pilot turn in the seat toward the fuel selector handle, then the pilot motioned with his hand that things were all right. The technician did not observe whether the pilot had repositioned the fuel selector. The pilot restarted the engine, taxied, took off, and performed three touch-and-go landings in a span of about 26 minutes, followed by a straight-out departure to the west. Ground witnesses saw the airplane in straight and level flight about 350 to 500 feet over a residential area, then they heard a reduction of engine noise. The airplane was seen to pitch slightly nose up, then it banked sharply to the right & descended nose first into the ocean. The major structural components of the airframe were found fragmented on the ocean floor near the engine, but no preimpact part failure was found. The fuel selector valve was found in an intermediate position, about 1/3 open between the engine feed line and the right tank, and about 2-4% open to the left tank. Tests using another engine showed that the engine could be operated at full power with the selector in the as-found position; however, when the cap was removed from the left port (simulating the effect of an empty left tank), fuel pressure dropped to less than 1/2; & within a few seconds, the engine lost power. Conditions were simulated using another Long-EZ to evaluate the maneuver required to switch tanks from the front seat. The simulation revealed that 4 actions were required to change the fuel selector in flight: 1) Remove pilot's hand from the control stick; 2) Rotate upper body to the extreme left to reach the fuel selector handle; 3) Loosen shoulder harness; 4) Rotate the handle to a non-marked (not logically oriented) position. During the evaluation, investigators noted a natural reaction for the pilot's right foot to depress the right rudder pedal when turning in the seat to reach the fuel selector handle. With the right rudder depressed in flight, the airplane would pitch up slightly & bank to the right.

Brief of Accident (Continued)

LAX98FA008
FILE NO. 1406 10/12/97 PACIFIC GROVE, CA AIRCRAFT REG NO. N555JD TIME (LOCAL) - 17:28 PDT

Occurrence# 1 Phase of operation LOSS OF ENGINE POWER (TOTAL) - NOMECHANICAL CRUISE

Findings

1. FUEL SYSTEM, SELECTOR/VALVE
2. ACFT/EQUIP, INADEQUATE CONTROL LOCATION - OWNER/BUILDER
3. FUEL SYSTEM, SELECTOR/VALVE - UNMARKED
4. ENGINE INSTRUMENTS, FUEL QUANTITY GAGE - INADEQUATE
5. ENGINE INSTRUMENTS, FUEL QUANTITY GAGE - UNMARKED
6. PREFLIGHT PLANNING/PREPARATION - INADEQUATE - PILOT IN COMMAND
7. REFUELING - NOT PERFORMED - PILOT IN COMMAND
8. FUEL TANK SELECTOR POSITION - IMPROPER - PILOT IN COMMAND
9. FLUID, FUEL - STARVATION/EXHAUSTION

Occurrence# 2 Phase of operation

LOSS OF CONTROL - IN FLIGHT
EMERGENCY DESCENT/LANDING

Findings

10. REMEDIAL ACTION - ATTEMPTED
11. RUDDER - INADVERTENT ACTIVATION - PILOT IN COMMAND
12. DIVERTED ATTENTION - PILOT IN COMMAND
13. INADEQUATE TRANSITION/UPGRADE TRAINING
14. LACK OF TOTAL EXPERIENCE IN TYPE OF AIRCRAFT - PILOT IN COMMAND

Occurrence# 3 Phase of operation

IN FLIGHT COLLISION WITH TERRAIN/WATER
DESCENT - UNCONTROLLED

Findings

15. TERRAIN CONDITION - WATER

The National Transportation Safety Board determines the probable cause(s) of this accident was: the pilot's diversion of attention from the operation of the airplane and his inadvertent application of right rudder that resulted in the loss of airplane control while attempting to manipulate the fuel selector handle. Also, the Board determined that the pilot's inadequate preflight planning and preparation, specifically his failure to refuel the airplane, was causal. The Board determined that the builder's decision to locate the unmarked fuel selector handle in a hard-to-access position, unmarked fuel quantity sight gauges, inadequate transition training by the pilot, and his lack of total experience in this type of airplane were factors in the accident.



National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: February 3, 1999

In reply refer to: A-99-9

Mr. Tom Poberezny
President
Experimental Aircraft Association
Post Office Box 3086
Oshkosh, Wisconsin 54093-3086

On October 12, 1997, about 1728 Pacific daylight time, an experimental category, amateur-built Adrian Davis¹ Long-EZ airplane, N555JD, crashed into the Pacific Ocean near Pacific Grove, California. Air traffic control communications indicated that the airplane had departed from the Monterey Peninsula Airport's runway 28L about 1712, and the pilot performed three touch-and-go landings and departed to the west moments before the accident. Witnesses reported that they heard engine popping and a reduction in engine noise before the accident. The pilot made no distress calls. The pilot was killed, and the airplane was destroyed.

An airport maintenance technician helped the pilot push the airplane out of the hangar before the accident flight and was present during the preflight check. The technician said he told the pilot that less than a quarter tank of fuel was available in the left tank and less than half a tank of fuel was available in the right tank. The technician estimated the fuel quantity based on the assumption that the presentations on the unmarked sight gauges were linear. However, Long-EZ fuel tank sight gauges are not linear, and examination of other Long-EZ sight gauges revealed that the actual fuel on-board the airplane would have been much lower than the technician's estimate. The fuel tank sight gauges were not visible from the front cockpit. The technician loaned the pilot a shop inspection mirror so it would be possible for the pilot to see the fuel tank sight gauges in flight. The pilot told the technician that he did not wish to refuel the airplane.

The technician said he heard the engine start and run for a short time and quit. Watching from the hangar, he saw the pilot turn in the front cockpit toward the fuel selector handle behind his left shoulder. Shortly afterward, the technician heard the engine restarted. The pilot signaled an "okay" to the technician and taxied toward the runway. After the airplane departed the traffic

¹ The Federal Aviation Administration (FAA) issues experimental airworthiness certificates for amateur-built aircraft with the original builder's name as the manufacturer. Any subsequent owner may change the registration number but not the Certificate of Airworthiness. Hence, the builder's name appears on the Certificate of Airworthiness.

pattern to the west, witnesses reported that the airplane climbed to 350 to 500 feet and was in level flight when, after the reduction in engine noise, it pitched slightly nose-up, entered a steep right bank, and descended nose-first into the ocean.

Safety Board investigators determined that the weight and center of gravity of the accident airplane were within the original planned limits for the Long-EZ and would not have affected the flight or stall characteristics of the airplane. Based on the airplane's fueling history, the technician's observations of the fuel levels at engine start, and the normal fuel consumption rates of the airplane's Lycoming O-320-E3D engine, the airplane would have had about 3 1/2 gallons of fuel available from the left tank and about 6 1/2 gallons of fuel available from the right tank. The Safety Board found that witness statements were consistent with the checkout pilot's description of postflight engine shut-down² and concluded that the engine lost power because of fuel starvation or exhaustion.³

The Long-EZ was designed by Rutan Aircraft Factory and amateur-built from the Rutan plans as a single-engine, tandem cockpit, swept-wing, canard-equipped⁴ airplane with laminar flow airfoils.⁵ The engine is mounted aft of the cabin, and both cockpits have pitch and roll side-stick controls.

The all-composite⁶ airplane has a canard with elevators for pitch control. The swept wings have taper and twist and have winglets installed at the tips. According to technicians from the Experimental Aircraft Association (EAA), the rudder system used in the Long-EZ is very sensitive⁷ in low-speed flight. According to the former Rutan chief engineer, the airplane has a substantial glide ratio due to its aerodynamically clean design but will pitch up and roll right when the airspeed is slow and the right rudder is depressed. When the airspeed is higher, he stated that roll rates are much higher and that it is possible to aileron-roll the airplane from rudder application only (ailerons neutral).

According to the Long-EZ owner's manual, the airplane has good flight characteristics at minimum speed. The manual describes "stalls" as maneuvers that result in increased aft stick force or mild pitch or roll oscillations. Spin attempts result in a spiral that reportedly can be recovered by neutralizing rudder and pulling out normally. The Long-EZ design incorporates many high performance features but would not be considered "high performance" by Federal

² The checkout pilot told Safety Board investigators that when the engine was stopped by closing the mixture (shutting off the fuel supply) at the end of a flight, loud popping normally occurred.

³ For more information, see Brief of Accident #LAX98FA008 (enclosed).

⁴ A canard is a lifting airfoil located in the front portion of an airplane that eliminates the need for a tail-mounted horizontal stabilizer.

⁵ Laminar flow airfoils are used in high performance, complex aircraft such as the Beech Starship. The airfoil construction minimizes drag but is sensitive to boundary layer separation (stall).

⁶ The Long-EZ airplane is constructed of shaped foam and fiberglass/epoxy materials.

⁷ The rudder system in the Long-EZ comprises two independent, outward acting rudders on the rear of the winglets. Activation in low speed flight is very easy; however, the owners manual cautions against inadvertent use because a substantial yaw will result.

Aviation Administration (FAA) definition⁸ because the airplane has no flaps or controllable pitch propeller. Nonetheless, its laminar flow airfoils have greater lift-to-drag ratios than most general aviation airplanes. Because the airplane has no flaps, its landing speeds are greater than many small airplanes, and it has a wings level, power off stall speed of about 71 mph.⁹

The Long-EZ airplane has two 26-gallon fuel tanks, one at each wing root. Fuel quantity is determined by viewing the rear cockpit sight gauges. N555JD was also equipped with a fuel totalizer.¹⁰ Fuel is selected from the left or the right tank by turning a fuel selector handle. According to the Rutan design, the fuel selector handle is to be located just aft of the nose wheel position window between the pilot's legs and is oriented toward the right to select the right tank, left to select the left tank, and another quarter turn to the left to select the "Off" position. A placard associated with the Rutan design clearly identifies the fuel selector handle positions.

The amateur builder of N555JD modified the fuel system design by locating the fuel selector handle on the left side of the bulkhead that forms the front cockpit seat back. It was positioned approximately behind the front-seat pilot's left shoulder (see figure 1). The builder also changed the orientation of the handle so that upward selected "Off," right selected the left tank, and downward selected the right tank. The corresponding 3-position fuel selector valve was installed inside the rear cockpit on the front of the engine firewall just behind the rear seat and was connected to the selector handle via two torque tubes and a universal joint. The selector handle was about 4 feet forward of the fuel selector valve. No placard or marking existed (nor was it required) on the fuel selector handle base that would have indicated to the pilot its operating position. Further, as has been stated, the sight gauges were not marked to quantify the amount of fuel in the tanks.

⁸ The FAA defines "high performance" as an airplane that has an engine with greater than 200 horsepower or that has retractable landing gear, flaps, and a controllable pitch propeller (14 Code of Federal Regulations (CFR) Part 61.31 (e)).

⁹ The maximum stall speed allowed for aircraft certificated under 14 CFR Part 23 is 61 knots (70 mph).

¹⁰ Although the accident airplane was equipped with sight gauges, which were part of the original design, it also had a fuel totalizer installed in the front instrument panel that required pilot entry of the starting fuel amount. Witness statements provide no evidence that the totalizer was used, and the checkout pilot stated he was not familiar with it and did not provide any instruction on its use.

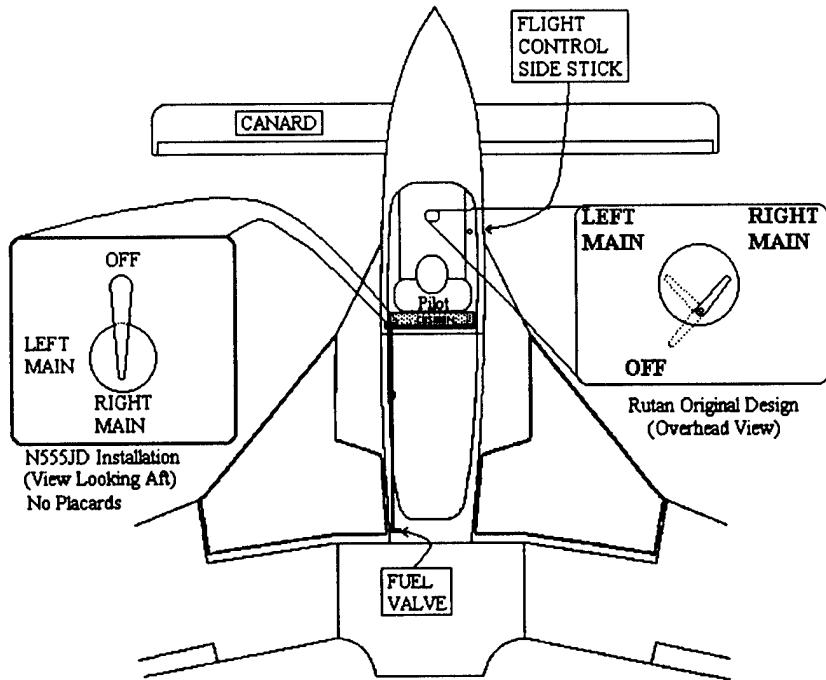


Figure 1—Comparison of fuel selector handle locations in Long-EZ

N555JD vs. Original design

The flight control side sticks in both cockpits were installed in armrests on the right side of the cockpits, measured about 6 inches high, and were similar in function to a conventional control stick. During the postaccident investigation, simulation by Safety Board staff showed that the front-seat pilot in the accident airplane would have had to loosen his shoulder harness, completely release the flight control stick, turn in his seat, and stretch to his left when reaching over the left shoulder with his right hand to change the position of the fuel selector handle on the accident Long-EZ airplane. The Safety Board investigator, in every simulation, inadvertently applied right rudder when turning his body and reaching for the fuel selector handle. This finding concerned the Safety Board because the design change that moved the fuel selector handle introduced a safety hazard in N555JD. On the basis of the accident circumstances and witness accounts, the Board concluded that the accident pilot probably inadvertently applied right rudder while manipulating the fuel selector, precipitating the loss of control that preceded the accident.

The fuel selector valve assembly from the accident airplane was found in an intermediate position; the selector valve port from the right tank fuel supply line was about 33 percent open to the engine feed line and the left was about 2 to 4 percent open to the engine feed line. An engine test run in a test cell showed that full power could be attained (with fuel in both tanks) with the selector valve in the "as found" position. However, with fuel in only one tank and the other fuel

line open to the atmosphere to simulate an empty tank, the engine lost power with the fuel selector valve in the "as found" position. The position of the fuel selector handle from the accident airplane could not be determined because of damage to the torque tubes between the valve and the selector handle.

Postaccident examination of the engine revealed no mechanical failures, and internal continuity of the drive train components was established. The magneto¹¹ was tested and produced a normal spark. The fuel lines had no leaks or blockages. The evidence indicated that the engine was capable of producing normal power if sufficient fuel was supplied to it.

The Safety Board determined that the probable cause of the accident was the pilot's diversion of attention from the operation of the airplane and his inadvertent application of right rudder that resulted in the loss of airplane control while attempting to manipulate the fuel selector handle. Also, the Board determined that the pilot's inadequate preflight planning and preparation, specifically his failure to refuel the airplane, was causal. The Board determined that the builder's decision to locate the unmarked fuel selector handle in a hard-to-access position, unmarked fuel quantity sight gauges, inadequate transition training by the pilot, and his lack of total experience in the type of airplane were factors in the accident.

N555JD had a special airworthiness certificate in the experimental category¹² that was issued on May 5, 1987. The airplane had been flown about 850 hours and had been sold two times since its construction. Because N555JD was an experimental, amateur-built airplane, specific deviations from the original plans did not require FAA approval nor was a placard required to identify fuel selector valve positions or to indicate that there had been a change in the airplane's design. However, the overall design is evaluated for safety and airworthiness by the FAA prior to issuing the experimental airworthiness certificate.

The Safety Board is concerned that the pilot of N555JD, who had minimal¹³ pilot-in-command experience in the accident airplane, may not have been adequately familiar with the operating positions of the unmarked fuel selector handle. This is of special concern because in its modified location and orientation, the fuel selector handle's operating positions would have been less intuitively obvious than if it had been installed as originally designed. Also, demonstrations indicated that the fuel selector handle was out of the accident pilot's view and in an awkward position that a pilot of similar height as the accident pilot (5' 10") could not operate without releasing the flight control stick. An interview with the checkout pilot revealed that he

¹¹ This engine had one magneto and one electronic ignition installed. The spark plugs showed evidence of normal ignition, and the magneto functioned normally when its impulse-coupling was rotated by hand. The electronic ignition was not tested.

¹² Title 14 CFR 21.191 "Experimental Certificates," allows experimental airworthiness certificates to be issued for, among other purposes, the operation of amateur-built aircraft. Amateur-built aircraft are not required to meet the standardized certification requirements contained in Part 23.

¹³ Safety Board investigators determined that the accident pilot had about 70 minutes of pilot-in-command experience in this model airplane, not including the accident flight. The pilot's flight experience will be discussed later in this recommendation letter.

had avoided this problem by planning his flights in the airplane such that he never needed to operate the fuel selector valve handle in flight.

Safety Board investigators found that there are numerous experimental category airplanes that are flown without placards and markings on cockpit instruments and essential system controls, such as the fuel selector handle. Further, essential cockpit controls, including fuel selectors in amateur-built airplanes, are not required to be in standardized locations. The Board is concerned that pilots inexperienced in such airplanes may find it difficult to operate them without type-specific training (type-specific training will be discussed later in this recommendation letter).¹⁴

FAA Order 8130.2C, "Airworthiness Certification of Aircraft and Related Products," provides guidance to FAA aviation safety inspectors regarding the issuance of special airworthiness certificates and operating limitations for experimental aircraft. Paragraph 88(b) of this order describes inspections necessary to obtain special airworthiness certificates. It indicates that all instruments should be marked according to the approved flight manual. Advisory Circular (AC) 20-27D "Certification and Operation of Amateur-Built Aircraft," provides guidance to pilots on building, certifying, and operating amateur-built aircraft and describes the FAA's role in the certification process. Paragraph 12 of AC 20-27D states that the applicant should expect the FAA inspector or the designated airworthiness representative (DAR)¹⁵ to verify that all required markings are properly applied. The FAA order and the AC, however, do not explicitly require the inspection of placards or markings in the cockpit before issuing special airworthiness certificates. They also do not provide adequate guidance or evaluation concerning the inspection of the placement or operation of essential controls. Because accident data from a Safety Board study suggest that the ergonomics of cockpit control placement can be critical in the safe operation of airplanes,¹⁶ the Board is concerned that a lack of requirements for standardized placards, markings, or appropriate placement of essential system controls could jeopardize flight safety in experimental, amateur-built airplanes. Therefore, the Safety Board believes that the FAA should amend FAA Order 8130.2C to specify that, before the issuance of special airworthiness certificates, experimental, amateur-built airplanes should be inspected for needed placards and markings on cockpit instruments and for the appropriate placement and operation of

¹⁴ Safety Board staff found that the Glasair training syllabus directed the pilot to answer multiple questions concerning, among other subjects, fuel system descriptions, operations, and emergency procedures.

¹⁵ DARs are private persons designated by the FAA to act in its behalf in the inspection of aircraft and to issue airworthiness certificates.

¹⁶ A 1974 NTSB special study, U.S. General Aviation Accidents Involving Fuel Starvation (AAS-74-01) analyzed fuel starvation aircraft accidents from 1970 through 1972. Among the recommendations in the report, which were intended to reduce the number of fuel starvation accidents, the Safety Board asked the FAA to amend 14 CFR Part 23 to include specifications for standardizing fuel selector valve designs, displays, and modes of operation (A-74-39). This recommendation was classified "Closed—Acceptable Action" after the FAA changed Part 23. Currently, 14 CFR Part 23.777 addresses the physical placement of controls and states that "each fuel feed selector control must...be located and arranged so that the pilot can see and reach it without moving any seat or primary flight control when his seat is at any position in which it can be placed." The mapping of fuel selector control positions in accordance with natural expectations is addressed in 14 CFR Part 23.779, which requires that fuel selector control movement be consistent with tank selection (i.e., left for left tanks; right for right tanks).

essential system controls to ensure that they provide clear marking, easy access, and ease of operation.

The Safety Board notes that the requirement for an annual inspection (referred to as a condition inspection)¹⁷ of experimental, amateur-built airplanes is contained in a limitations letter attached to the special certificate of airworthiness.¹⁸ Paragraphs 141 and 142 of Order 8130.2C generally describe the issuance of experimental operating limitations,¹⁹ which always include the inspection requirements. The operating limitations state that the condition inspection shall be recorded in the aircraft maintenance records in accordance with the scope and detail of 14 CFR Part 43, Appendix D or other FAA-approved programs and that the condition inspection is equivalent to an annual inspection.

The operations limitations may require the use of placards and markings to ensure the safe operation of the aircraft. The Safety Board is not aware of any recurrent requirement to inspect placards and markings in the cockpit and on essential system controls to ensure that they display appropriate and accurate information.

The Safety Board is concerned about the lack of requirements to periodically inspect the placards, markings, and essential controls in experimental, amateur-built aircraft. Periodic inspection of these items is necessary to ensure that they consistently display appropriate and accurate information to the pilot for flight safety. Therefore, the Safety Board believes that the FAA should amend FAA Order 8130.2C to specify that inspection limitations be issued with special airworthiness certificates for amateur-built airplanes requiring that the annual condition inspection include an inspection for needed placards and markings on cockpit instruments and the appropriate operation of essential controls to ensure that they provide clear marking, easy access, and ease of operation.

Another concern of the Safety Board was the limited amount of transition training received by the accident pilot in the accident airplane. A review of the pilot's FAA airman and medical records indicated that he held a private pilot certificate with airplane ratings for single and multiengine land, single-engine sea, instrument airplane, glider, and a Lear Jet type rating. The pilot's logbook was not recovered after the accident; however, his total flight time reported on his last physical was 2,750 hours, including 15 hours in the preceding 6 months. The Safety Board's investigation revealed that the pilot purchased the accident airplane on September 27, 1997, and that his pilot-in-command experience in the airplane was limited to a 1/2-hour ground and flight checkout on the day before the accident and a 1-hour solo flight. According to an air traffic control communication tape, the duration of the checkout flight was only 10 minutes, and the pilot departed about 20 minutes later for a 1-hour solo flight to his home airport. The Safety Board learned that the pilot had been on three previous demonstration flights in Long-EZ airplanes (during all of which he occupied the rear seat) but could not determine how much, if

¹⁷ Condition inspection is defined in the Airworthiness Inspector's Handbook, FAA Order 8300.10, Chapter 25.

¹⁸ The limitations letter lists requirements for continued airworthiness.

¹⁹ The operating limitations are designed for each aircraft. The FAA inspector may impose any operational limitations deemed necessary in the interest of safety.

any, pilot training he received during these flights.²⁰ The Safety Board found no evidence of the pilot having any other flight experience in Long-EZ airplanes.

On the basis of his limited flight experience in this type of airplane, the Safety Board concludes that the pilot likely did not have the necessary knowledge and skills to efficiently operate it during the emergency circumstances of the accident flight. Had the pilot been more skilled in the operation of the flight controls and knowledgeable of the unusual fuel selector, the accident might have been avoided or the severity of the accident could have been reduced.²¹

The Safety Board is aware that some advanced,²² experimental, amateur-built airplane training organizations have published training syllabi. The Safety Board also notes that insurers²³ of amateur-built airplanes, similar to or more advanced than the Long-EZ, have sometimes required a training syllabus and detailed aircraft inspection as conditions for providing insurance coverage for the pilot/owner. The Safety Board has found that the accident rates for high performance, complex, and unusual aircraft may be substantially reduced by requiring pilot/owner-operators to undergo type-specific ground and flight training. For example, it was found that when formal flight and ground training was required for pilots of Piper PA-46 Malibu airplanes, the fatal accident rate in that airplane model was reduced.²⁴ Further, the Aviation Insurance Association (AIA) has reported that using and closely adhering to a specified training syllabus has considerably reduced the accident rate in the Glasair and Lancair experimental, amateur-built airplanes.²⁵ Additionally, the Safety Board found accident rates of Robinson R22 helicopters were substantially reduced when, in response to the Safety Board's recommendations, the FAA issued Special Federal Aviation Regulation (SFAR) 73 on February 23, 1995,

²⁰ According to the Rutan engineer who gave the first demonstration flight, the pilot said he had no previous flights in Long-EZ airplanes. Only one demonstration flight was in N555JD.

²¹ The in-flight manipulation of the fuel selector, the location and accuracy of the fuel quantity sight gauges, and using the installed fuel totalizer probably would have been included in formalized transition training.

²² "Advanced" experimental airplanes are typically faster, aerodynamically cleaner, and are more complex than most amateur-built aircraft. The Safety Board staff found three companies that sell kits for experimental, amateur-built airplanes and that provide formal, type-specific ground and flight training to the owner/pilots of these airplanes. The Glasair training plan provides for approved certificated flight instructors located in different areas of the country that will conduct the formal course of instruction to the pilot. The Lancair plan provides ground instruction at its factory and provides a factory test pilot to fly at the builder's location in the builder's airplane through the first 10 hours of the flight test program. The Velocity plan has east and west coast centers that provide formal ground and flight instruction. Safety Board staff found that each company, in conjunction with insurers, mandates its specific course of training. Each of these formal programs provides certification to the insurers of the experimental, amateur-built airplane when pilots complete the prescribed training.

²³ According to the AIA, accident rates for the Glasair and Lancair airplanes have dramatically dropped because of insurers requiring pilots' use of type-specific training syllabi.

²⁴ A spokesman for AVEMCO (a major aircraft insurer) reported to the Safety Board that, as a condition of insurance, his company requires that all PA-46 pilots (and pilots of other pressurized airplanes) attend formal training that includes completion of a type-specific training syllabus. These programs reportedly reduced the accident rates of these airplanes. The Safety Board's accident data show no PA-46 fatal accidents during 1992 and 1997, 1 in 1993, 2 in 1998, and 3 in 1994, 1995, and 1996, respectively. None of the accidents' probable causes is attributed to inadequate transition training.

²⁵ The AIA has reported that by requiring type-specific transition training in conjunction with the airplane manufacturer, the accident rates for those aircraft were significantly lowered.

promulgating special training, proficiency, and operational rules for pilots operating these helicopters.²⁶ The SFAR required specific training in this highly responsive helicopter before a pilot could operate it as the pilot-in-command.

A 1998 query showed that the FAA's aircraft database contains about 20,244 experimental, amateur-built aircraft, including 1,200 Long-EZ airplanes.²⁷ According to the EAA, about 8,000 additional aircraft were in the process of being built by amateur builders in 1997, and in the next few years, a significant number of amateur-built airplanes will be sold to non-builders. As previously mentioned, experimental, amateur-built aircraft are not required to be certificated to 14 CFR Part 23 certification standards and, therefore, may well have control locations, functions, and markings that do not conform to the original design plans. Because of these and other differences (such as performance and handling characteristics) between experimental, amateur-built aircraft and Part 23 aircraft, quality transition training²⁸ of pilots flying them is critical to their safe operation.

The Safety Board is aware of the EAA's Flight Advisor Program, which is designed to help amateur airplane builders safely perform their first flight. In this program, advisors with substantial flying/building experience offer free advice, videos, and written guidance to help make builders' first test flight a safe one. The advisors do not provide flight training but offer training suggestions and options for the pilot to consider. This program, which the EAA claims has resulted in reduced first-flight accident rates,²⁹ is generally known among EAA members but not among the general pilot population.

Such programs can provide an added margin of safety for pilots inexperienced in the operation of unusual or unique, non-Part 23-certificated aircraft. Unfortunately, no FAA ACs, pamphlets, or programs exist that require or encourage pilots who did not build their experimental category airplanes to receive type-specific transition flight training. FAA publications and programs also lack emphasis on the benefits of formalized syllabi for such transition training. The Safety Board concludes that an expanded flight advisor program could substantially reduce the experimental, amateur-built airplane accident rate. Therefore, the Safety Board believes that the EAA should establish, in conjunction with the FAA and the AIA, a cooperative program that strongly encourages pilots transitioning to unusual or unfamiliar amateur-built, experimental category airplanes to undergo formalized, type-specific transition training similar to that provided to pilots of some advanced, experimental, amateur-built airplanes.

²⁶ For more information, see NTSB Special Investigation Report, NTSB/SIR-96/03, Robinson Helicopter Company R22 Loss of Main Rotor Control Accidents, dated April 2, 1996.

²⁷ According to the EAA, 4,500 Long-EZ plans were sold. The EAA estimates that about 95,000 plans or kits have been sold to prospective amateur builders of all aircraft types in the past 10 years.

²⁸ The Safety Board considers quality transition training to be type-specific, formal transition training that adheres to a training syllabus.

²⁹ The EAA has reported significant accident rate reductions since the Flight Advisor program was started in 1995.

Therefore, the National Transportation Safety Board recommends that the Experimental Aircraft Association:

Establish, in conjunction with the Federal Aviation Administration and the Aviation Insurance Association, a cooperative program that strongly encourages pilots transitioning to unusual or unfamiliar amateur-built, experimental category airplanes to undergo formalized, type-specific transition training similar to that provided to pilots of some advanced, experimental, amateur-built airplanes. (A-99-9)

Also as a result of its investigation, the Safety Board issued Safety Recommendations A-99-5 through -7 to the FAA and A-99-8 to the AIA.

The National Transportation Safety Board is an independent Federal agency with the statutory responsibility "...to promote transportation safety by conducting independent accident investigations and by formulating safety improvement recommendations" (Public Law 93-633). The Safety Board is vitally interested in any actions taken as a result of its safety recommendations and would appreciate a response from you regarding action taken or contemplated with respect to the recommendation in this letter. Please refer to Safety Recommendation A-99-9 in your reply.

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred with this recommendation.

By: 
Jim Hall
Chairman

Enclosure

National Transportation Safety Board
Washington, D.C. 20594

Brief of Accident

Adopted 01/26/99

LAX98FA008
FILE NO. 1406 10/12/97 PACIFIC GROVE, CA AIRCRAFT REG NO. N555JD TIME (LOCAL) - 17:28 PDT

MAKE/MODEL	-ADRIAN DAVIS-LONG-EZ
ENGINE MAKE/MODEL	-Lycoming O-320-E3D
AIRCRAFT DAMAGE	-Destroyed
NUMBER OF ENGINES	-1
OPERATING CERTIFICATES	-NONE
TYPE OF FLIGHT OPERATION	-Personal
REGULATION FLIGHT CONDUCTED UNDER	-14 CFR 91
HOMEBUILT	

LAST DEPARTURE POINT DESTINATION	- MONTEREY, CA - Local
AIRPORT PROXIMITY	- Off airport/airstrip
AIRPORT NAME	- MONTEREY PENINSULA
RUNWAY IDENTIFICATION	- 28L
RUNWAY LENGTH/WIDTH (Feet)	- 7598/150
RUNWAY SURFACE	- Asphalt
RUNWAY SURFACE CONDITION	- Dry
PILOT-IN-COMMAND	AGE - 53
CERTIFICATES/RATINGS	Private
	Single-engine land, Multiengine land, Single-engine sea
INSTRUMENT RATINGS	Glider
	Airplane

LAST 90 DAYS	FLIGHT TIME (Hours)
TOTAL ALL AIRCRAFT	- 2750
TOTAL MAKE/MODEL	- Unk/Nr
TOTAL INSTRUMENT TIME	- 2
	Unk/Nr

The pilot had recently purchased the experimental, amateur-built Long-EZ airplane, which had a fuel system that differed from the designer's plans. The original builder had modified the fuel system by relocating the fuel selector handle from a position between the front pilot's legs to a position behind & above his (or her) left shoulder. There were no markings for the operating positions of the fuel selector handle, which were up (for off), down (for the right tank), and to the right (for the left tank). This deviation from the original design plans did not require FAA approval, nor did it require a placard to indicate such change from the original design. On 10/11/97 at Santa Maria, CA, the pilot received a 1 1/2-hour flight and ground checkout in the airplane by another Long-EZ pilot. The checkout pilot reported that the pilot needed a seatback cushion to be in position to reach the rudder pedals, and that he had difficulty reaching the fuel selector handle while seated with the cushion added. The pilot then departed on a 1-hour

flight to his home base at Monterey with an estimated 12.5 gallons of fuel in the right tank & 6.5 gallons in the left tank. The checkout pilot estimated about 9 gallons of fuel were needed for the flight, and he noted the fuel selector was positioned to the right tank before departure. On 10/12/97 (the next day), a maintenance technician assisted the pilot in preparing for another flight. During preflight, the pilot was not observed to visually check the fuel. The technician noted that when the pilot was seated in the airplane, he had difficulty reaching the fuel selector handle. Also, he gave the pilot a mirror to look over his shoulder to see the unmarked, non-linear, fuel sight gauges, which were located in the rear cockpit. The technician estimated the available fuel and advised the pilot that the left tank indicated less than 1/4 full and that the right tank indicated less than 1/2 full. He said his estimate was based on the assumption that the gauges were accurate and linear. The pilot declined an offer for additional fuel, saying he would only be airborne about 1 hour and did not need fuel. The technician observed that before the engine was started, the fuel selector handle was in a vertical position; however, he did not note whether it was up (off) or down (right tank). As the technician went to the hangar, he heard the engine start & run for a short time, then quit. He saw the pilot turn in the seat toward the fuel selector handle, then the pilot motioned with his hand that things were all right. The technician did not observe whether the pilot had repositioned the fuel selector. The pilot restarted the engine, taxied, took off, and performed three touch-and-go landings in a span of about 26 minutes, followed by a straight-out departure to the west. Ground witnesses saw the airplane in straight and level flight about 350 to 500 feet over a residential area, then they heard a reduction of engine noise. The airplane was seen to pitch slightly nose up; then it banked sharply to the right & descended nose first into the ocean. The major structural components of the airframe were found fragmented on the ocean floor near the engine, but no preimpact part failure was found. The fuel selector valve was found in an intermediate position, about 1/3 open between the engine feed line and the right tank, and about 2-4 $\frac{1}{2}$ open to the left tank. Tests using another engine showed that the engine could be operated at full power with the selector in the as-found position; however, when the cap was removed from the left port (simulating the effect of an empty left tank), fuel pressure dropped to less than 1/2; & within a few seconds, the engine lost power. Conditions were simulated using another Long-EZ to evaluate the maneuver required to switch tanks from the front seat. The simulation revealed that 4 actions were required to change the fuel selector in flight: 1) Remove pilot's hand from the control stick; 2) Loosen shoulder harness; 3) Rotate upper body to the extreme left to reach the fuel selector handle; & 4) Rotate the handle to a non-marked (not logically oriented) position. During the evaluation, investigators noted a natural reaction for the pilot's right foot to depress the right rudder pedal when turning in the seat to reach the fuel selector handle. With the right rudder depressed in flight, the airplane would pitch up slightly & bank to the right.

Brief of Accident (Continued)

LAX96PA008
FILE NO. 1406 10/12/97 PACIFIC GROVE, CA AIRCRAFT REG NO. N555JD TIME (LOCAL) - 17:28 PDT

Occurrence# 1 Phase of operation LOSS OF ENGINE POWER (TOTAL) - CRUISE - NONMECHANICAL

Findings

1. FUEL SYSTEM, SELECTOR/VALVE
2. ACFT/EQUIP, INADEQUATE CONTROL LOCATION - OWNER/BUILDER
3. FUEL SYSTEM, SELECTOR/VALVE - UNMARKED
4. ENGINE INSTRUMENTS, FUEL QUANTITY GAGE - INADEQUATE
5. ENGINE INSTRUMENTS, FUEL QUANTITY GAGE - UNMARKED
6. PREFLIGHT PLANNING/PREPARED - INADEQUATE - PILOT IN COMMAND
7. REFUELING - NOT PERFORMED - PILOT IN COMMAND
8. FUEL TANK SELECTOR POSITION - IMPROPER - PILOT IN COMMAND
9. FLUID, FUEL - STARVATION/EXHAUSTION

Occurrence# 2 Phase of operation LOSS OF CONTROL - IN FLIGHT
EMERGENCY DESCENT/LANDING

Findings

10. REMEDIAL ACTION - ATTEMPTED
11. RUDDER - INADVERTENT ACTIVATION - PILOT IN COMMAND
12. DIVERTED ATTENTION - PILOT IN COMMAND
13. INADEQUATE TRANSITION/UPGRADE TRAINING
14. LACK OF TOTAL EXPERIENCE IN TYPE OF AIRCRAFT - PILOT IN COMMAND

Occurrence# 3 Phase of operation IN FLIGHT COLLISION WITH TERRAIN/WATER
DESCENT - UNCONTROLLED

Findings

15. TERRAIN CONDITION - WATER

The National Transportation Safety Board determines the probable cause(s) of this accident was: the pilot's diversion of attention from the operation of the airplane and his inadvertent application of right rudder that resulted in the loss of airplane control while attempting to manipulate the fuel selector handle. Also, the Board determined that the pilot's inadequate preflight planning and preparation, specifically his failure to refuel the airplane, was causal. The Board determined that the builder's decision to locate the unmarked fuel selector handle in a hard-to-access position, unmarked fuel quantity sight gauges, inadequate transition training by the pilot, and his lack of total experience in this type of airplane were factors in the accident.



National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: FEB 19 1999

In reply refer to: A-99-10 and -11

Honorable Jane F. Garvey
Administrator
Federal Aviation Administration
Washington, D.C. 20591

On February 9, 1998, N845AA, a Boeing 727-223 (B-727), operating as American Airlines flight 1340, landed 180 feet short of the runway 14R threshold at the Chicago O'Hare International Airport while attempting a category II instrument landing system approach. Of the 116 passengers and 6 crewmembers on board, 22 passengers and 1 crewmember reported minor injuries. The airplane was substantially damaged.

During the ground impact sequence, the main landing gear and aft air stairs separated from the airplane, and the nose gear folded back into the avionics compartment. The airplane came to rest on its fuselage along the south side of runway 14R and 2,245 feet from the initial impact point.

Although the investigation continues, the Safety Board has identified two safety issues that affect the safety and survivability of passengers and their rapid egress during an emergency evacuation.

The first safety issue was the blockage of the aisle to the forward entry door (L-1) and the partial blockage of the forward galley door (R-1 exit) caused by the open door to the stowage compartment (formerly used to stow liferafts) near the R-1 exit. Also, several of the overhead ceiling panels separated from their support structure, but they did not block the aisle because lanyards attached to the panels and ceiling supports prevented them from falling down completely.

The B-727 is equipped with four single door liferaft ceiling stowage compartments that contain liferafts when the airplane is being operated as an extended over-water flight. For flights that are not operated over water, the stowage compartments may be empty. The 4 X 2 foot door panels are latched along their forward and aft edges; however, the doors were not equipped with any device to prevent them from falling down and blocking the aisle. The ceiling panels installed fore and aft of the liferaft stowage compartments were equipped with lanyards that limit their downward travel and prevent the panel from blocking the aisle.

The Safety Board previously addressed a similar issue during its investigation of the United Airlines B-747-122, N4713U, accident near Honolulu, Hawaii, on February 24, 1989. The accident involved the in-flight separation of a cargo door and subsequent emergency landing and evacuation of the airplane. During the accident, two liferaft stowage compartments had opened downward and blocked the R-2 and L-2 exits. In its accident report, the Safety Board issued Safety Recommendation A-90-59, which asked the Federal Aviation Administration (FAA) to do the following:

Issue an airworthiness directive (AD) to require that stronger latches be installed in oversized storage compartments that formerly held liferafts on all B-747 airplanes and also limit the distance that these compartments can be opened.

On October 7, 1991, the FAA issued AD 91-22-05, applicable to B-747s. The AD required the replacement of overhead stowage compartment doors with improved doors and improved counterbalance assemblies and operational checks of associated equipment for certain stowage compartments located near entry doors or the deactivation of those compartments. Based on the issuance of the AD, the Board classified Safety Recommendation A-90-59 "Closed—Acceptable Action" on November 1, 1991.

The safety recommendation and the AD were not applicable to commercial transport-category airplanes other than B-747s. The Safety Board is concerned that if there had been a need for immediate evacuation, rapid egress would not have been possible at door L-1 because it was blocked by the open liferaft stowage compartment. Also, a liferaft stowage compartment door could open during a hard landing or turbulence and could injure a flight attendant. Thus, the Safety Board believes that the FAA should identify all airplanes operated under Title 14 Code of Federal Regulations Part 121 with liferaft ceiling stowage compartments or compartments that formerly held liferafts that open downward and issue an AD to limit the distance that those compartments can open.

The second safety issue that the Safety Board has identified in its investigation of the flight 1340 accident involved two passenger seatbelts that released at their seat attachments during the airplane's impact with the ground. The seatbelts on the aisle side of seats 25C and 27C remained buckled but became unhooked at their seat shackles. The passenger in seat 25C was not injured; he stated that he noticed that his seatbelt had separated (at the seat attachment) when he reached down to unbuckle it. However, the passenger in seat 27C reported minor injuries; he stated that his seatbelt released during the airplane's second impact. After his seatbelt released, he pitched forward to the left, and struck the seat in front of him.

Both seatbelt assemblies are of a design commonly used in commercial airplanes. The seatbelt assembly consists of the standard release buckle, webbing, and an attachment fitting with a spring clip keeper at each end of the belt (see figure 1). The attachment fitting clips over a shackle that is bolted to the seatframe.

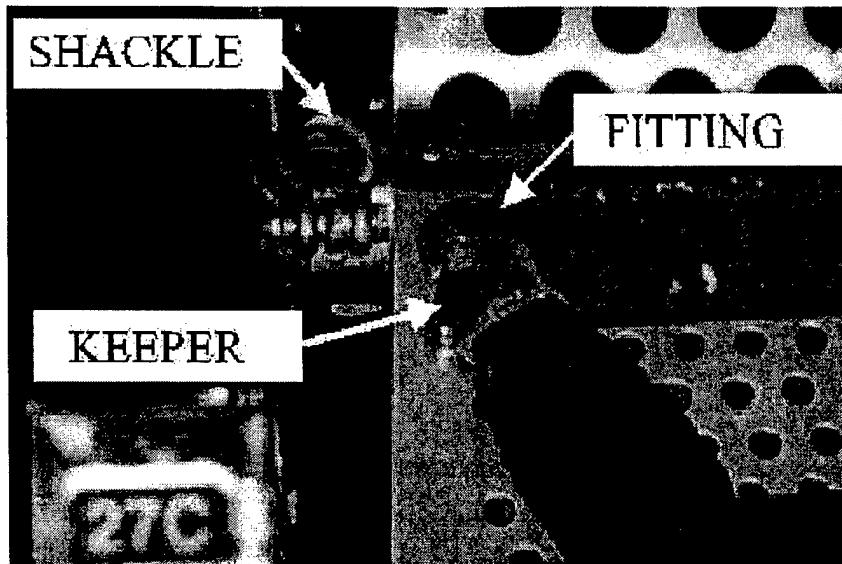


Figure 1.—Seatbelt Assembly

The Safety Board has previously addressed the issue of seatbelts becoming unhooked. During its investigation of a British Aircraft BAC-1-11 that encountered severe turbulence near Orlando, Florida, on May 24, 1988, the Safety Board found that three passenger seatbelts had detached during the turbulence. The passengers were displaced in their seats and sustained minor injuries. Safety Board investigators and Civil Aeromedical Institute (CAMI) engineers conducted tests at CAMI to identify ways that seatbelt attachment fittings could detach from the shackles bolted to the seatframes. The tests revealed that when the bolt used to fasten the shackle to the seatframe is overtightened, the shackle cannot move vertically to self-center, preventing the seatbelt end fitting from centering on the shackle. When this condition occurs, the end fitting cannot align with the seat occupant, and minimal side loads can force open the end fitting's spring-loaded keeper and detach the end fitting from the shackle.

Consequently, the Safety Board issued Safety Recommendations A-90-20 and A-90-21, which asked the FAA to do the following:

A-90-20

Issue a maintenance alert to principal maintenance inspectors (PMIs) to inspect seatbelt attachment shackles installed on passenger seats on air carrier, air taxi, and commercial airplanes to verify that the correct bolts are used to fasten the shackles to the seats, the bolts are torqued to the correct value, and the shackles are free to self-center after the correct torque has been applied to the bolts.

A-90-21

Require PMIs to verify that air carrier, air taxi, and commercial operators have maintenance instructions for the proper installation of passenger seatbelt attachment shackles.

On May 3, 1991, the FAA issued Notice 8300.101, "Seatbelt Maintenance Requirements." The notice identified seatbelt maintenance discrepancies and recommended that PMIs alert operators of the need to inspect seatbelt attachment shackles to ensure that correct shackle bolts are installed, the bolts are torqued to the correct value, and the shackles are free to self-center after the correct torque has been applied to the bolts. The notice also asked PMIs to review and ensure that the carrier's maintenance and inspection procedures include periodic inspection of seatbelt restraint systems; notify the air carrier, in writing, of any problems or discrepancies that require changes to the inspection program; inspect and replace unserviceable seatbelts during ramp and en route inspections; and ascertain that quality control and assurance exists to maintain the integrity of seatbelts and restraints. The Safety Board subsequently classified the recommendations "Closed—Acceptable Action."

During the investigation of the American Airlines flight 1340 accident, Safety Board investigators examined the seatbelt shackles at seats 25C and 27C. In contrast to the CAMI findings in the earlier detachments, both shackles were found to move freely in the vertical direction, and the torque values for each shackle bolt did not exceed the recommended torque limits of 65- to 90-inch pounds. The Safety Board was unable to determine why the seatbelts became unhooked from the shackles at seats 25C and 27C.

On April 18, 1998, a seatbelt released from its seat attachment when a Boeing 747-200, N623FF, operated by Tower Air, Inc. as flight 37, encountered turbulence about 120 nautical miles east of Kennebunkport, Maine, at flight level 350. Investigation of the incident revealed that a passenger's seatbelt released at seat 58F during the encounter with turbulence and that a flight attendant had reattached the seatbelt to its shackle after the turbulence had ended.

The Safety Board is concerned that the current seatbelt fitting with a spring clip keeper that clips over a shackle does not provide enough assurance that the seatbelt will remain fastened to a seat during turbulence or during an emergency landing. The Safety Board is also concerned that operators may not be aware of this unsafe condition and that appropriate corrective measures have not been taken to alert operators and to prevent this condition from occurring. Thus, the Safety Board believes that the FAA should reexamine the design of seatbelts installed on passenger seats on air carrier, air taxi, and commercial airplanes to determine the reason some have become unhooked from their seat attachments during turbulence or a hard landing and establish a suitable means of ensuring that the seatbelts remain attached to their shackles during all modes of flight.

Therefore, the National Transportation Safety Board recommends that the Federal Aviation Administration:

Identify all airplanes operated under Title 14 Code of Federal Regulations Part 121 with liferaft ceiling stowage compartments or compartments that formerly held liferafts that open downward and issue an airworthiness directive to limit the distance that those compartments can open. (A-99-10)

Reexamine the design of seatbelts installed on passenger seats on air carrier, air taxi, and commercial airplanes to determine the reason some have become unhooked from their seat attachments during turbulence or a hard landing and establish a suitable means of ensuring that the seatbelts remain attached to their shackles during all modes of flight. (A-99-11)

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in these recommendations.



By: Jim Hall
Chairman



National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: February 22, 1999

In reply refer to: A-99-12 through -15

Honorable Jane F. Garvey
Administrator
Federal Aviation Administration
Washington, D.C. 20591

On March 30, 1998, Royal Airlines flight 311, a Boeing 727-212 airplane, registered in Canada as C-FRYS, experienced an uncontained failure¹ of the low pressure turbine (LPT) in the No. 2 engine, a Pratt & Whitney (P&W) JT8D-17A, during the takeoff roll at the Fort Lauderdale-Hollywood International Airport, Fort Lauderdale, Florida. The flightcrew reported that at approximately 100 knots, they felt a thud, and the engine fail light in the cockpit illuminated. The takeoff was rejected, and the No. 2 engine fire warning light illuminated. The flightcrew discharged both fire extinguishing bottles into the No. 2 engine nacelle, stopped the airplane on an adjacent taxiway, and initiated an evacuation of the airplane. Of the 186 revenue passengers, 2 infants, and 8 flight crewmembers on board, 10 passengers sustained injuries during the evacuation. The airplane was operating on an instrument flight rules flight plan under the provisions of 14 Code of Federal Regulations Part 129 as an international charter passenger flight from Fort Lauderdale to Toronto, Canada.

Because the airplane was operated by a Canadian-certificated air carrier, the Transportation Safety Board of Canada assisted in the National Transportation Safety Board's investigation under the provisions of Annex 13 to the International Convention on Civil Aviation. Because the engine had been previously repaired by Volvo Flygmotor AB,² Trollhättan, Sweden, the Safety Board was also assisted by the Swedish Board of Accident Investigation during the review of the failed engine's repair records.

The examination of the airplane revealed that the No. 2 engine's left and right aft cowl doors had numerous penetrations and fire-blistered paint just aft of the LPT; however, the airplane sustained no other damage. The fire was caused by fuel and oil from several severed lines in the aft section of the engine.

¹ An uncontained engine failure occurs when an internal part of the engine fails and is ejected through the cowling or causes other pieces of the engine to be ejected through the cowling.

² Volvo Flygmotor AB has since changed its name to Volvo Aero Corporation.

The JT8D engine's low pressure rotor system is made up of a two-stage fan, which consists of the 1st and 2nd stage fan rotors,³ and a four-stage low pressure compressor (LPC), which consists of the 3rd, 4th, 5th, and 6th stage compressor rotors. The two-stage fan and four-stage compressor are joined to the three-stage LPT, which consists of the 2nd, 3rd, and 4th stage turbine rotors, by a drive shaft, all of which rotate as one unit under normal conditions (see figure 1). The examination of the incident engine revealed that the 1st and 2nd stage fan rotors and the 3rd stage compressor rotor rotated together but independently from the remainder of the low pressure rotor system from the 4th stage compressor rotor rearward. The examination also showed that the 2nd, 3rd, and 4th stage LPT disks were intact but that all of the LPT blades were fractured adjacent to the blade root platforms, and most of the LPT vanes were missing. Although the engine was outfitted with an LPT containment shield, as required by Airworthiness Directive (AD) 94-20-09, the containment shield was broken into three pieces, and the engine was cut in two just aft of the LPT by liberated LPT blades.⁴

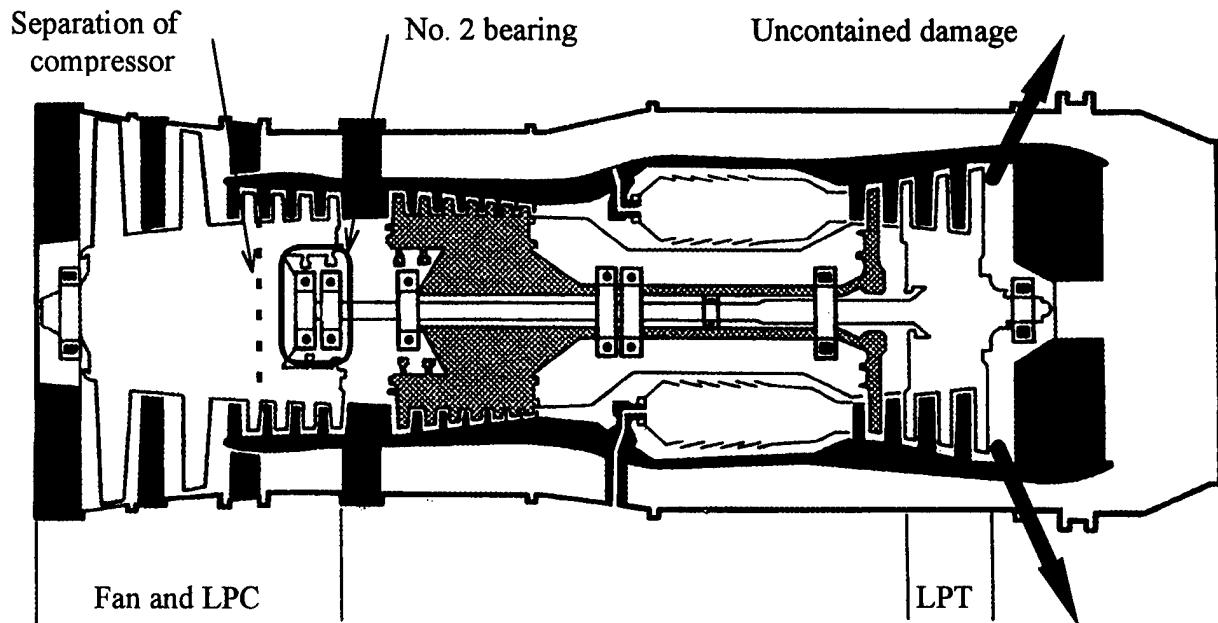


Figure 1. JT8D engine

The 4 stages of the JT8D engine's LPC are held together by 12 long bolts, called LPC rear tierods, that pass through alternating disks and spacers (see figure 2). The disassembly of the Royal Airlines LPC revealed that one LPC rear tierod, part number (PN) 789550, was fractured transversely across the tierod's 4th stage compressor disk land.⁵ The entire fracture face on the

³ A rotor stage refers to the compressor or turbine disk or hub and the respective installed blades.

⁴ The aft section of the engine and thrust reverser assembly remained attached to the airplane by the aft engine mount cone bolt.

⁵ A tierod compressor disk land is a larger diameter section of the tierod that passes through the compressor disk's tierod hole. The diameter of the tierod compressor disk land is about 0.010 inch less than the diameter of the compressor disk's tierod hole.

tierod had surface corrosion, suggesting that the tierod had been broken for some time. Because of overstress, the 11 remaining LPC rear tierods were fractured at their forward ends between the 3rd stage compressor disk lands and the tierod nut threads. All six of the recovered tierod nuts and ends had numerous pockmarks on one side, and the tierod ends were bent away from the pockmarks. The pockmarks and bending damage suggest that after the initial tierod fractured and was liberated from the compressor, it tumbled around in the cavity at the front of the LPC and impacted the other tierod nuts and ends until they eventually fractured, causing the compressor to separate between the 3rd and 4th stage rotors and the engine to fail. Eleven equally spaced fan exit vanes had the imprints of the tierod nuts on the leading edge, indicating that the 11 remaining tierods fractured simultaneously when the engine failed.

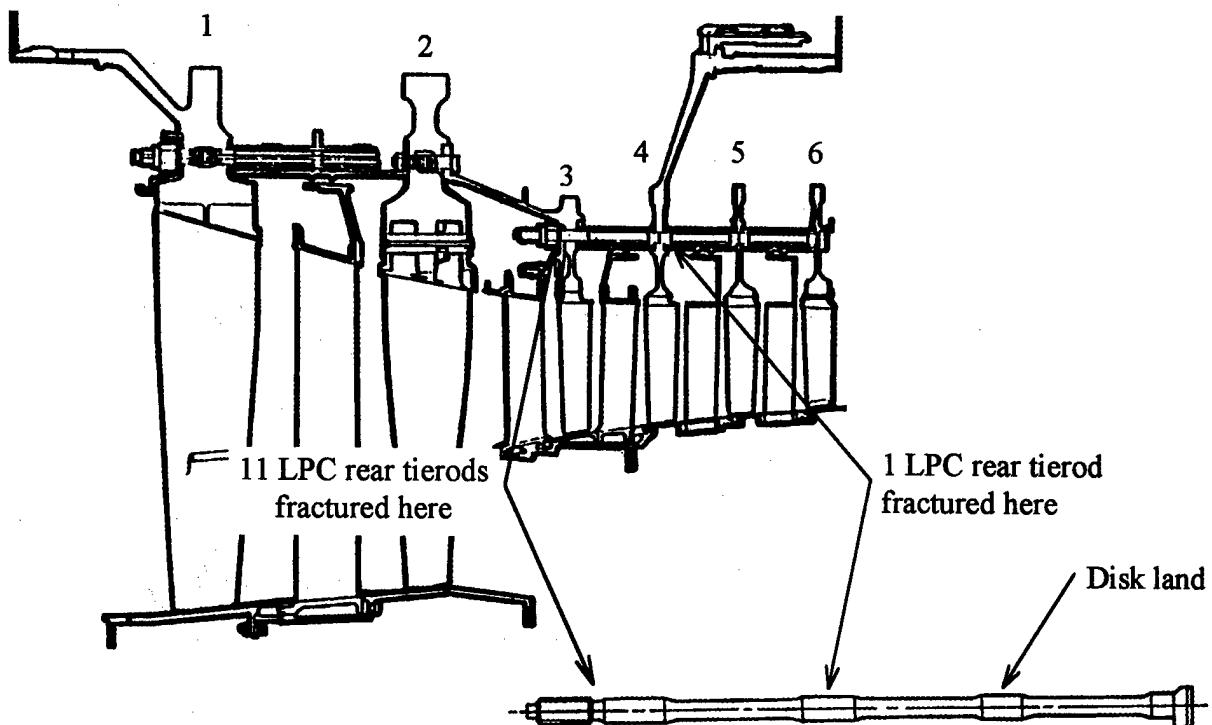


Figure 2. Cross-section of the JT8D fan and LPC and view of an LPC rear tierod

The Safety Board's examination of the LPC rear tierod with the corroded fracture face revealed that a fatigue fracture originated from a small area of galling⁶ on the 4th stage compressor disk land. On July 7, 1982, as a result of 33 LPC rear tierod fractures at the 3rd and 4th stage disk land locations that caused damage in JT8D engines, P&W issued Service Bulletin (SB) 5407.⁷

⁶ Galling is a condition whereby excessive friction between high spots results in localized welding with the subsequent tearing and flaking away of material that further roughens one or both of the rubbing surfaces.

⁷ Although a review of Federal Aviation Administration service difficulty reports identified only 1 event of an LPC rear tierod fracture, P&W advised that as of September 17, 1998, it had received reports of 133 events of LPC rear tierod fractures in JT8D-1 through -17AR engines.

SB 5407 introduced into the JT8D-9 through -17AR engines, the PN 789550 LPC rear tierod, which differs from the old part only in that it is required to have an antigalling coating applied to the tierod's compressor disk lands. SB 5407 also introduced PN 789552 and 789553 LPC rear tierods into the JT8D-1 through -7B engines and PN 789774 LPC rear tierods into the JT8D-9 through -17 engines. All of these new parts are also required to have the antigalling coating applied to the tierod's compressor disk lands. For newly manufactured tierods, the antigalling coating is required to be applied to the compressor disk lands at the time of manufacture; but, for previously operated tierods, the antigalling coating can be applied when the parts are being repaired and the part is then reidentified with the appropriate part number. P&W indicated that the SB should be complied with when the LPC rotor module was disassembled sufficiently to afford access to the tierods. However, no AD was issued to mandate the installation of the tierods with the antigalling coating.

The accident engine's maintenance records show that the engine, including the LPC, had been repaired by Volvo Flygmotor AB, on November 26, 1987, and on April 18, 1991.⁸ The records for the 1987 repair show that SB 5407 had been complied with by the installation of 12 new PN 789550 LPC rear tierods in the engine. The records for the 1991 repair show that the LPC rear tierods were removed, visually inspected in accordance with the JT8D engine manual,⁹ and after being found serviceable, reinstalled in the LPC. The postaccident energy dispersive x-ray spectroscopy examination of the compressor disk lands on the initially fractured tierod and the other 11 LPC rear tierods in the engine's LPC did not detect any trace of the primary constituents of the antigalling coating specified in the SB. Therefore, the Safety Board concludes that the antigalling coating was not applied to the new LPC rear tierods by P&W at the time of manufacture. P&W stated that the Royal Airlines engine failure has been the only one that involved the fracture of an LPC tierod that was supposed to have been coated with the antigallant. The lack of the antigalling coating on all 12 of the LPC rear tierods in the Royal Airlines engine suggests the problem may be widespread since it is unlikely that if only 12 tierods were manufactured without the antigalling coating, that all of them would be installed in the same engine. Therefore, the Safety Board believes that the Federal Aviation Administration (FAA) should require that all P&W JT8D-1 through -17AR engines be disassembled at the next shop visit and that the LPC rear tierods be removed, cleaned, stripped of any antigallant and nickel cadmium (nicad),¹⁰ non-destructively inspected, replated with nicad, coated with the antigallant, and reinstalled or that new tierods coated with the antigallant be installed.

The Safety Board notes that the JT8D engine manual requires a fluorescent penetrant inspection (FPI)¹¹ for the high pressure turbine (HPT) tierods¹² and that the JT8D-200 engine

⁸ At the time of both repairs, the engine was owned and operated by Sterling Airways, a Danish supplemental air carrier that subsequently ceased operations. The engine also received a hot section inspection by Gas Turbine Corporation, East Granby, Connecticut, on August 24, 1995, but the LPC was not disassembled at that time.

⁹ JT8D Engine Manual Task 72-33-13 Insp-01.

¹⁰ Nicad is a two-step plating process of cadmium over nickel and is used as a corrosion preventative.

¹¹ FPI is a non-destructive inspection (NDI) method of detecting cracks and other surface anomalies. The inspection consists of applying to or immersing a part in a low-viscosity penetrating fluid containing fluorescent dyes and allowing the fluid to penetrate into any surface defects. Excess penetrant is removed and a developer is applied that acts as a blotter to draw the penetrant out from any surface defects, which will then luminesce when viewed under a blacklight.

manual¹³ requires a magnetic particle inspection (MPI)¹⁴ for that engine's LPC tierods¹⁵ and an FPI for the high pressure compressor and HPT tierods.¹⁶ However, the JT8D engine manual requires only a visual examination for the LPC rear tierods. The Safety Board is concerned that a visual inspection may not adequately determine the serviceability of these parts. Therefore, the Safety Board believes the FAA should require P&W to revise its JT8D engine manual to require that the LPC rear tierods be inspected with an appropriate non-destructive inspection (NDI) method.

Although the engine was equipped with an LPT containment shield, as required by AD 94-20-09, turbine blade fragments were still liberated through the engine cases and nacelle when the engine failed. A dimensional inspection of the LPC and LPT disks revealed that the 6th stage LPC disk and the 2nd, 3rd, and 4th stage LPT disks had grown diametrically. When a compressor or turbine disk exceeds its rotational speed limit, the extreme centrifugal loads that occur from the overspeed cause plastic deformation of the part, increasing its diametrical dimensions.

In a letter to the Safety Board, P&W stated that its analysis of the disks' growth indicated that the low pressure rotor had experienced a 140 percent overspeed of the rotor's rotational speed limit. In its letter, P&W further stated that the JT8D engine's LPT containment shield had been designed and demonstrated to withstand the impacts from fractured blade pieces at speeds of up to 120 percent of the rotor's rotational speed limit. (In the JT8D engine, a 120 percent overspeed of the LPT rotor can occur during an LPT shaft fracture event.) In the JT8D engine, a significant amount of the rotational energy produced by the LPT is required to drive the two fan stages compressing the air entering the engine. When the limiting force of the fan stages is suddenly removed from the LPT, as might occur in an LPT shaft fracture or as occurred in the Royal Airlines engine separation, the LPT rotor rapidly accelerates and exceeds its rotational speed limit. However, in an LPT shaft fracture event, the LPT rotor, as it accelerates, will also translate rearward rapidly and the blades will mesh¹⁷ with the LPT vanes to break up the airfoils into small fragments and limit the rotor speed to about 120 percent of the rotational speed limit.

In the Royal Airlines event, the separation of the fan stages and 3rd stage compressor rotor from the rest of the LPC was in front of the No. 2 bearing, which is the thrust bearing for the LPC

¹² JT8D Engine Manual Task 72-52-05 Insp-01.

¹³ The JT8D and JT8D-200 engines are separately type certificated and are treated separately with regard to engine manuals and maintenance.

¹⁴ MPI is an NDI method of detecting cracks and other defects in ferromagnetic materials such as iron or steel. The inspection consists of magnetizing a part with high amperage, direct current electricity, thus creating magnetic lines of flux, then applying or immersing the part in a liquid containing ferromagnetic particles in suspension. The ferromagnetic particles align themselves with the magnetic lines of flux on the surface of the part forming a pattern. If a discontinuity is present in the material on or near the surface, opposing magnetic poles form on either side of the discontinuity and the pattern is disrupted, forming an indication of a crack. An indication assumes the approximate size and shape of the surface projection of the discontinuity; however, indications are more visible when defects are approximately perpendicular to the magnetic lines of flux.

¹⁵ JT8D-200 Engine Manual Task 72-33-13.

¹⁶ JT8D-200 Engine Manual Tasks 72-36-20 and 72-52-05, respectively.

¹⁷ Meshing is the desired clashing of the turbine blades and vanes following a turbine rotor shaft fracture that is intended to decelerate the rotor and to break the blades into small particles, thus reducing the likelihood of blades penetrating an engine casing.

in the JT8D engine. Because the thrust bearing is designed to absorb the axial loads of the low pressure rotor, it prevented the rearward movement of the LPT. Consequently, the LPT rotor in the Royal Airlines engine was able to accelerate to about 140 percent of the rotational speed limit before the LPT blades fractured because the desired meshing action was not able to occur. When the LPT blades did fracture, they were likely full or almost full length in comparison to the small fragments that would have resulted if the blades and vanes had meshed. As a result of the larger mass of the airfoils at the 140 percent overspeed, the fractured LPT blades were able to penetrate the containment shield, engine cases, and nacelle.

The Safety Board is concerned that an LPC rear tierod fracture can lead to an uncontained engine failure because it is likely that there are other LPC rear tierods in service without the antigalling coating that may be subject to fracture. Further, because of the size of the JT8D-1 through -17AR operating fleet and the length of time between shop visits, it will likely be several years before all affected engines will be disassembled to permit an NDI of the LPC rear tierods. Therefore, the Safety Board believes the FAA should require a repetitive borescope inspection of P&W JT8D-1 through -17AR engines to check for fractured LPC rear tierods and, if found, require the removal of those engines from service for repair. Periodic reinspections should continue until an NDI of the LPC rear tierods is performed or the tierods are replaced.

A visual inspection of several new PN 789550 JT8D LPC rear tierods with the antigalling coating applied showed only a subtle color difference between the nicad plating and antigalling coating. It was possible, with a focused inspection in optimal lighting conditions, to discern the light gray color of the antigalling coating from the light greenish-silver background color of the nicad plating. However, the Safety Board is concerned that if lighting conditions are less than optimal, if the inspection is not focused on the subtle color difference between the nicad and antigalling coatings, or if the tierods have discolored slightly in service, a shop technician may not be able to readily detect the presence or absence of the antigalling coating on these tierods. The shop technician who installed the LPC rear tierods on the accident engine could have reasonably assumed that the tierods were coated with antigallant at manufacture, as required, and therefore, might not have examined the parts closely to check for its presence. However, if the antigallant were readily observable, the technician would likely have noticed its absence.

The Safety Board is aware that many special coatings are applied to parts used throughout the aviation industry and that these special coatings are not generally visually distinct so as to be readily detectable. Thus, the problem of being able to identify whether a part has the appropriate coating applied is not just limited to JT8D LPC rear tierods, but exists for many coated parts used in aviation. Therefore, the Safety Board believes that the FAA should evaluate, and if feasible, implement the use of dyes and other means to ensure coatings and surface treatments are easily detectable so that shop technicians can determine if the necessary coatings have been applied to a part before installation in an engine or airplane.

Therefore, the National Transportation Safety Board recommends that the Federal Aviation Administration:

Require that all Pratt & Whitney JT8D-1 through -17AR engines be disassembled at the next shop visit and that the low pressure compressor rear tierods be removed, cleaned, stripped of any antigallant and nickel cadmium (nicad), non-destructively inspected, replated with nicad, coated with the antigallant, and reinstalled or that new tierods coated with the antigallant be installed. (A-99-12)

Require Pratt & Whitney to revise its JT8D engine manual to require that the low pressure compressor rear tierods be inspected with an appropriate non-destructive inspection method. (A-99-13)

Require a repetitive borescope inspection of Pratt & Whitney JT8D-1 through -17AR engines to check for fractured low pressure compressor (LPC) rear tierods and, if found, require the removal of those engines from service for repair. Periodic reinspections should continue until a non-destructive inspection of the LPC rear tierods is performed or the tierods are replaced. (A-99-14)

Evaluate, and if feasible, implement the use of dyes and other means to ensure coatings and surface treatments are easily detectable so that shop technicians can determine if the necessary coatings have been applied to a part before installation in an engine or airplane. (A-99-15)

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in these recommendations.

By: 
Jim Hall
Chairman



National Transportation Safety Board

Washington, D.C. 20594

Safety Recommendation

Date: March 9, 1999

In reply refer to: A-99-16 through -18

Honorable Jane Garvey
Administrator
Federal Aviation Administration
Washington, D.C. 20591

On May 11, 1996, the crew of ValuJet flight 592, a DC-9-32, reported smoke and fire shortly after departing Miami, Florida. The flight recorders stopped about 40 to 50 seconds before the airplane crashed on its return to the airport, killing all 111 passengers and crew.

On July 7, 1996, TWA flight 800, a Boeing 747-100, on an international passenger flight from New York to Paris, exploded about 13 minutes after takeoff as it was climbing through 13,700 feet. Both flight recorders stopped at the time of the explosion, but the airplane did not hit the water off Long Island, New York, for another 40 to 50 seconds. All 230 people aboard the airplane were killed.

On December 19, 1997, SilkAir flight 185, a Boeing 737, entered a rapid descent from 35,000 feet, which ended with a high speed impact in the Sumatran River near Palembang, Indonesia. There were 104 fatalities. The Indonesian investigation, in which the Safety Board participated, determined that both flight recorders stopped prior to the airplane entering the rapid descent.

On September 2, 1998, Swissair flight 111, an MD-11, on a regularly scheduled passenger flight from New York to Geneva, Switzerland, diverted to Halifax after the crew reported smoke in the cockpit; the airplane crashed into the waters near Peggy's Cove, Nova Scotia, killing all 229 passengers and crew on board. Thus far, the Canadian Transportation Safety Board's (TSB) investigation, which is being conducted in close cooperation and coordination with the National Transportation Safety Board and Swiss investigative authorities, has been severely hampered by the lack of data from the cockpit voice recorder (CVR) and digital flight data recorder (DFDR), which stopped nearly 6 minutes before the airplane hit the water.

These recent accidents are just the latest in a long history of accident and incident investigations that were hindered by the loss of flight recorder data due to the interruption of aircraft electrical power. The following list contains only some of the more notable accidents for

which vital flight recorder information was not available because of a premature loss of electrical power:

- Overseas National Airways (ONA) flight 032, a DC-10-30; JFK Airport, New York; November 12, 1975. During the takeoff roll, the right engine ingested a large number of sea gulls and disintegrated causing the loss of electrical power to the flight data recorder. The airplane and CVR were destroyed by the postcrash fire. An ONA employee occupying the flight deck observer seat captured the takeoff roll on a movie camera with audio, which became the only record of the accident sequence. There were no fatalities among the 139 passengers and crew.
- Southern Airways flight 242, a DC-9-31; New Hope, Georgia; April 4, 1977. Following the airplane's penetration of a level 6 thunderstorm, both engines failed. The pilots attempted a dead-stick landing on a two-lane highway. Both recorders stopped following the engine failures and did not resume operation until 2 minutes 4 seconds later, when the auxiliary power unit was started. There were 62 fatalities and 23 survivors.
- American Airlines flight 191, a DC-10-10; Chicago O'Hare Airport; May 25, 1979. The pylon of engine No. 1 failed during takeoff rotation, after which the engine separated from the airplane, removing power to a portion of the DFDR sensors and the CVR. The airplane crashed 32 seconds later. There were no survivors among the 271 passengers and crew. Two people on the ground were also killed.
- United Airlines flight 811, a Boeing 747-122; Honolulu, Hawaii; February 24, 1989. Engines No. 3 and 4 were shut down because of foreign object damage from the right forward cargo door, which separated causing extensive damage to the fuselage and adjacent passenger cabin. The CVR was lost for 21.4 seconds during the emergency descent as a result of engine shutdown. There were nine fatalities.

Since 1983,¹ there have been 52 accidents and incidents, including the 4 recent accidents mentioned above, in which information from either a CVR or FDR or both were lost due to interruption of electrical power following an engine or generator failure or crew action. Until recently, recorder technology did not offer a practical solution to the problem of loss of electrical power to the on-board recorders. However, recent innovations in recorder and power supply technologies have made it possible to provide an independent power source that would provide sufficient power to operate a solid-state flight recorder for 10 minutes.

In assessing the feasibility of an independent power source, strong consideration must be given to reliability, complexity, maintainability, and cost. The independent power source must also automatically engage when power to the recorders is lost. Older model tape-based recorders require too much electrical power and are not easily adapted to a direct current (d.c.) battery or capacitor. However, the relatively low power requirements of solid-state flight recorders (about

¹ Origin date of the Safety Board's current aviation accident database. Data prior to 1983 are incomplete.

10 to 12 watts from a 28-volt d.c. system) would permit the use of an independent power source. Thus, it is evident that the use of an independent power source would also require the use of solid-state flight recorders.

The replacement of magnetic tape flight recorders with solid-state flight recorders would not appear to be an undue burden on the industry. In fact, several major U.S. air carriers have recognized the economic benefits of solid-state recorders and are replacing the obsolete tape flight recorders in their fleets with solid-state units solely for economic reasons. Further, replacement units exist that meet the latest Technical Standard Order (TSO)² standards and that are capable of recording 2 hours of CVR audio.

Other factors have also influenced the industry's movement to solid-state flight recorders. The poor survivability and performance of magnetic tape flight recorders in recent years have raised concerns in the United States and abroad about the ability of that medium to provide data of sufficient quality for accident and incident investigations. In several recent accidents, the magnetic tape flight recording medium was destroyed or damaged due to postaccident fire or water immersion. These accidents were in addition to those that lead to the markedly improved crash/fire survivability standards in TSOs C123a and C124a.³

Another factor is that the future serviceability of magnetic tape recorders is also in doubt. Of the tape flight recorders received by the Safety Board for readout, laboratory staff have noted an increase in the number of tape units with unreliable data and units that are partially or completely unserviceable. The Bureau Enquetes-Accidents, the French accident investigation authority, has had similar experiences and is developing a recommendation that would ban the Fairchild F800⁴ magnetic tape flight recorder because of its unreliability. The decline in serviceability is reminiscent of the serviceability problems experienced during the final years of the oscillographic foil flight recorders.

An additional consideration is the fact that magnetic tape flight recorders are no longer in production, and only a few manufacturers produce the precision instrumentation tape decks needed for playback of tapes recovered from accident-involved recorders. Some recorder manufacturers have also indicated a substantial decrease in the number of suppliers of tape recorder parts such as drive motors and magnetic heads. One manufacturer predicts that its stockpile of magnetic tape may be depleted by 2005.

Another significant factor that would warrant the industry to replace magnetic tape flight recorders with solid-state flight recorders involves the future requirement to record data link communications. In about 2004 to 2005, analog CVRs will no longer meet the requirements for aircraft using controller-pilot data link (CPDL) communications. It is anticipated that future regulatory changes will require that aircraft using CPDL communications be fitted with solid-

² TSOs detail the minimum performance standards for specified articles—such as materials, parts, and appliances—used on civil aircraft. TSOs are issued by the FAA Administrator.

³ The TSOs were developed in response to the Safety Board's Safety Recommendations A-92-45 through -48.

⁴ L-3 Communications, Inc., is the current manufacturer of Fairchild aviation recorders.

state CVRs (SSCVRs) that can record data link messages.⁵ To that end, the Safety Board encourages the industry to consider for future CVR installations on airplanes using controller-pilot data link communications that the CVRs be capable of recording digital data link messages.

As the technology and application of data link communications evolve, the industry will also need to consider developing the capability that enables qualified ground personnel to perform real-time monitoring of the flight parameters to assist the flight crew when an in-flight problem or emergency occurs. Such monitoring will require a communications network that is capable of transmitting real-time flight data to qualified ground personnel.

Current regulations call for a CVR with a minimum 30-minute recording duration. This minimum requirement was based on the limitations of 1960s recorder technology, which was constrained by the amount of magnetic tape that could be impact/fire protected. In the years since CVRs became mandatory, the Safety Board has investigated many accidents and incidents for which the 30-minute CVR recording was not sufficient to retain key events. This prompted the Safety Board to recommend in 1996 that all newly manufactured CVRs be SSCVRs with a 2-hour recording duration (Safety Recommendation A-96-171).⁶ Accident investigations in which the Safety Board has participated subsequent to the issuance of Safety Recommendation A-96-171 continue to demonstrate that a lack of recorded voice and other aural information can inhibit safety investigators and delay or prevent the identification of safety deficiencies.

The CVR installed on Swissair flight 111 used a continuous-loop magnetic tape with a 30-minute duration. The earliest information on the CVR tape was recorded about 15 minutes before the crew noted an unusual odor. Crew conversations and cockpit sounds prior to the beginning of this 30-minute recording might have provided insight into any initiating or precursory events that led to the accident.

About 38 minutes prior to the crew noting an unusual odor, Boston Center⁷ issued flight 111 a radio frequency change. During the following 13 minutes, Boston Center made repeated attempts to contact flight 111 but did not establish contact. Any cockpit conversations, flight deck noises, or attempted crew transmissions that occurred during this period were subsequently overwritten on the CVR, and thus were not available to the accident investigators.

Although 30-minute magnetic tape CVRs are no longer being manufactured, units still exist and could be installed on aircraft today. Given the continued need for longer periods of recorded sound to capture the initiating events of aviation accidents, and the availability of and trend toward 2-hour CVRs, the Safety Board believes that a retrofit program is warranted. Therefore, the Safety Board believes that the Federal Aviation Administration (FAA) should require the retrofit after January 1, 2005, of all CVRs on all airplanes required to carry both a

⁵ The FAA has indicated that it will initiate rulemaking to clarify that the present requirement to record all voice messages be expanded to include cockpit data messages. According to the FAA, the rulemaking is expected to take effect about 2004.

⁶ The current status of Safety Recommendation A-96-171 is "Open—Acceptable Response."

⁷ Boston Center is an FAA Air Route Traffic Control Center (ARTCC).

CVR and a FDR with a CVR that meets TSO C123a and is capable of recording the last 2 hours of audio.

Although a number of options were identified for assessing the feasibility of an independent power source, a capacitor appears to be the most effective means of providing an independent power source. The capacitor method would provide a power source that requires very little maintenance, and, unlike a rechargeable battery, the capacitor method would not require any power sensing circuitry for normal operation. To maximize recorder reliability and to minimize any crew intervention, the independent power source should automatically engage whenever the normal electrical power to the recorder ceases, even when the aircraft is powered down normally. To increase the probability of recording accident data, the independent power source should be capable of powering the recorder for 10 minutes after main power to the recorder shuts off.

For a DFDR, an independent power source would not necessarily enable the recording of any additional information. Backup power to a DFDR would result only in the recording of data from sensors that are still powered and can relay that information to the DFDR. If aircraft power is lost, the probability is small that the sensors and data acquisition unit would still be receiving power or be able to relay that data to the DFDR. However, in the case of a CVR, the area microphone is powered by the CVR; as long as the CVR receives power, the area microphone will continue to operate and the CVR will continue to record sounds from the area microphone, provided that the connection between the microphone and the recorder is not compromised. In the case of the SilkAir accident, the 2-hour SSCVR stopped recording 5 minutes 58 seconds prior to the DFDR stopping, which stopped 1 minute 54 seconds prior to impact. Thus, any valuable dialog in the cockpit regarding the airplane status for those 7 minutes 52 seconds was lost.

However, providing a 30-minute CVR with 10 minutes of independent power after main power ceases would result in about one-third of the in-flight audio being recorded over. Thus, it would not be acceptable to fit 30-minute CVRs with an independent power supply that automatically engages when aircraft electrical power is terminated for any reason.

With maintenance-free independent power sources, it is now feasible to provide an independent power source for new-technology CVRs for a specific period of time, in the event that aircraft power sources to the CVR are interrupted or lost. Therefore, the Safety Board believes that for the CVR retrofit after January 1, 2005, the FAA should also require the CVR to be provided with an independent power source that is located with the CVR and that automatically engages and provides 10 minutes of operation whenever aircraft power to the recorder ceases, either by normal shutdown or by a loss of power to the bus.

The Canadian TSB shares the view that a CVR retrofit is warranted and has developed a similar recommendation, which was issued to the Canadian and European regulators in early March 1999. The Safety Board and the TSB hope that the actions recommended by the two investigative authorities are adopted by civil aviation regulators worldwide.

The Safety Board recognizes that in the case of ValuJet flight 592 and TWA flight 800, the microphone wiring may, in fact, have been compromised and, consequently, the implementation of this retrofit would probably not have materially benefited the investigation of those accidents. However, other changes that are discussed in the following paragraphs—such as dual combination recording systems, with one being placed as close to the cockpit as possible—could have resulted in obtaining additional critical information.

As discussed earlier, it would not be practical to provide FDRs with an independent power source. However, if the FDR were part of a dual combination voice and data recorder system, an independent power source should be installed. Combination recorders are now available and provide the functions of both a DFDR and a CVR in a solid-state format; they do not require more space than the current DFDR models; they weigh less than the combined weights of a DFDR and a CVR; and they cost less than the combined costs of a DFDR and a CVR. In addition, combination recorders will allow for the use of dual redundant recorders, with one recorder located in close proximity to the cockpit to reduce the possibility of signal loss, and one as far aft as practicable to enhance survivability.

One particular problem that has occurred in several accidents, such as ValuJet flight 592 and TWA flight 800, is that either the aircraft's electrical power bus had been severed or the signal wires connecting the CVR/DFDR to the aircraft's sensors had been compromised. The CVR and DFDR are intentionally located in the rear of the aircraft for greater survivability. This rear mounting usually results in long cable runs from the forward cockpit areas to the recorders. One option for mitigating the risks to both recorder and cable survivability would be to locate one combination recorder in the rear of the aircraft and another combination recorder near or in the cockpit of the aircraft. This installation would virtually eliminate the vulnerability of the signal wires to external damage. As a result, the probability of the loss of power to the combination recorder due to an in-flight fire or breakup would decrease. The additional, forward-mounted combination recorder would also be fitted with an independent power source; consequently, if primary aircraft power were lost, the independent power source would further ensure that the combination recorder continued to record via the cockpit area microphone.

Therefore, the Safety Board believes that the FAA should require all aircraft manufactured after January 1, 2003, that must carry both a CVR and a DFDR to be equipped with two combination (CVR/DFDR) recording systems. One system should be located as close to the cockpit as practicable and the other as far aft as practicable. Both recording systems should be capable of recording all mandatory data parameters covering the previous 25 hours of operation and all cockpit audio including CPDL messages for the previous 2 hours of operation. The system located near the cockpit should be provided with an independent power source that is located with the combination recorder, and that automatically engages and provides 10 minutes of operation whenever normal aircraft power ceases, either by normal shutdown or by a loss of power to the bus. The aft system should be powered by the bus that provides the maximum reliability for operation without jeopardizing service to essential or emergency loads, whereas the system near the cockpit should be powered by the bus that provides the second highest reliability for operation without jeopardizing service to essential or emergency loads.

Until recently, it has been the general practice of aircraft manufacturers to use different aircraft electrical buses to provide power to the CVR and FDR; however, there has never been a requirement to do so. Current regulations call for power only from an electrical bus that provides the maximum reliability for operation without jeopardizing service to essential or emergency loads. As a result, MD-11 airplanes, which are currently configured with the CVR and FDR on the same generator bus, meet all regulatory requirements. However, with this configuration on MD-11 airplanes, such as Swissair flight 111, the failure or disabling of that bus would cause the loss of both flight recorders. Consequently, the Safety Board believes that CVRs, FDRs, and redundant combination flight recorders should be powered from separate generator buses. Therefore, the Board believes that the FAA should amend Title 14 *Code of Federal Regulations* Parts 25.1457 (cockpit voice recorders) and 25.1459 (flight data recorders) to require that CVRs, FDRs, and redundant combination flight recorders be powered from separate generator buses with the highest reliability. The Canadian TSB has developed a similar recommendation, which was issued to the Canadian and European regulators in early March 1999.

In its report on a September 8, 1989, incident involving USAir flight 105, a Boeing 737, at Kansas City, Missouri, the Safety Board cited the need for a video recording of the cockpit environment.⁸ The report pointed out the limitations of existing flight recorders to fully document the range of the flight crew actions and communications. It also noted that the introduction of aircraft with electronic "glass" cockpits and the future use of CPDL communications would enable the flight crew to make display and data retrieval selections that will be transparent to the CVR and FDR. The Safety Board indicated that it would monitor and evaluate progress in the application of video technology to the cockpits of air transports. In the 9 years since that incident, considerable progress has been made in video and flight recorder technologies, and the need for video recording is becoming more evident. Video recording of the cockpit environment on newly manufactured airplanes is now technologically and economically feasible, and interest in video recording is growing.

The international aviation community is aware of the safety benefits of crash-protected video recorders. Agenda item 3 of ICAO's FLIRECP/2⁹ specifically dealt with the need for standards and recommended practices (SARPs) concerning video recordings. The panel agreed that the use of video recordings in the aircraft cockpits would be very useful and noted that EUROCAE¹⁰ was developing minimum operational performance specifications (MOPs). The panel agreed that video technology was maturing to the point where specific technical aspects (for example, video frame rate, number of cameras, and resolution per frame) must be determined, and that the ongoing work of EUROCAE and ARINC¹¹ should be considered when developing video recorder SARPs. The panel concluded that it was "strongly committed to the

⁸ National Transportation Safety Board. 1990. *USAir Flight 105; Boeing 737-200, N283AU; Kansas City International Airport, Missouri; September 8, 1989*. Aircraft Incident Report NTSB/AAR-90/04.

⁹ International Civil Aviation Organization (ICAO), Flight Recorder Panel second meeting (FLIRECP/2).

¹⁰ European Organisation for Civil Aviation Equipment (EUROCAE).

¹¹ ARINC, located in Annapolis, Maryland, is a private corporation whose principal stockholders are international air carriers. ARINC provides the aviation industry with communications and information processing systems and services, system engineering, and standards.

introduction of video recordings in an appropriate and agreed format, and that this should form part of the future work of the panel."

EUROCAE Working Group 50 (WG50) began drafting the fundamental needs for video recorders at its February 1999 meeting, which was attended by recorder manufacturers, regulatory authorities, and accident investigators from around the world, including the Safety Board and the FAA. The fundamental needs for video recording are expected to be completed at the next meeting of WG50 in June 1999. Although WG50 remains committed to the task of defining standards for video flight recorders, it has not yet projected a completion date for a MOP.

The Safety Board believes that recorder systems and standard-setting processes should be flexible enough to incorporate new technology as it is developed. To that end, the Safety Board encourages the FAA and the aviation industry to take steps such as prewiring aircraft, developing system interfaces, and developing technical standards to facilitate the eventual introduction of new technology, such as video recorders.

Therefore, the National Transportation Safety Board recommends that the Federal Aviation Administration:

Require retrofit after January 1, 2005, of all cockpit voice recorders (CVRs) on all airplanes required to carry both a CVR and a flight data recorder (FDR) with a CVR that (a) meets Technical Standard Order (TSO) C123a, (b) is capable of recording the last 2 hours of audio, and (c) is fitted with an independent power source that is located with the digital CVR and that automatically engages and provides 10 minutes of operation whenever aircraft power to the recorder ceases, either by normal shutdown or by a loss of power to the bus. (A-99-16)

Require all aircraft manufactured after January 1, 2003, that must carry both a cockpit voice recorder (CVR) and a digital flight data recorder (DFDR) to be equipped with two combination (CVR/DFDR) recording systems. One system should be located as close to the cockpit as practicable and the other as far aft as practicable. Both recording systems should be capable of recording all mandatory data parameters covering the previous 25 hours of operation and all cockpit audio including controller-pilot data link messages for the previous 2 hours of operation. The system located near the cockpit should be provided with an independent power source that is located with the combination recorder, and that automatically engages and provides 10 minutes of operation whenever normal aircraft power ceases, either by normal shutdown or by a loss of power to the bus. The aft system should be powered by the bus that provides the maximum reliability for operation without jeopardizing service to essential or emergency loads, whereas the system near the cockpit should be powered by the bus that provides the second highest reliability for operation without jeopardizing service to essential or emergency loads. (A-99-17)

Amend Title 14 *Code of Federal Regulations* Parts 25.1457 (cockpit voice recorders) and 25.1459 (flight data recorders) to require that CVRs, FDRs, and redundant combination flight recorders be powered from separate generator buses with the highest reliability. (A-99-18)

If you have any questions about the recommendations, you may call (202) 314-6522.

Chairman HALL, Vice Chairman FRANCIS, and Members HAMMERSCHMIDT, GOGLIA, and BLACK concurred in these recommendations.



By: Jim Hall
Chairman